Appendix L

Capillary Break Design Report

AECOM

Prepared for:
PPG
Pittsburgh, PA

Prepared by:
AECOM
Chelmsford, MA
December 2017

Capillary Break Design
Final Report (Revision 2)

GAG-036K

Contents

List of Appendices

List of Tables

List of Figures

List of Acronyms and Abbreviations

%	percent
ACO	Administrative Consent Order
A-DGA	dense-grade aggregate amended with FerroBlack®-H
ASHHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
bgs	below ground surface
CCPW	Chromate Chemical Production Waste
Cr	chromium
Cr^{+3}	trivalent chromium
Cr^{+6}	hexavalent chromium
CEA	Classification Exception Area
CrSCC	Chromium Soil Cleanup Criteria
DGA	dense-grade aggregate
DO	dissolved oxygen
ft	feet or foot
GA	Garfield Avenue
GWQS	Groundwater Quality Standard
HDPE	high-density polyethylene
IRM	Interim Remedial Measure
JCO	Judicial Consent Order
JCRA	Jersey City Redevelopment Agency
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
mm	millimeter
MM	meadow mat
NAVD88	North American Vertical Datum of 1988
N.J.A.C.	New Jersey Administrative Code
NJDEP	New Jersey Department of Environmental Protection
oz	ounce
OGS	open-grade stone

ORP	oxidation-reduction potential
RAR	Remedial Action Report
RAWP	Remedial Action Work Plan
RIR	Remedial Investigation Report
SOW	statement of work
sy	square yard
TEP	Technical Execution Plan
µg/L	micrograms per liter

Executive Summary

This report presents the proposed capillary break design for the prevention of chromium blooms at the Garfield Avenue (GA) Group of Sites (Sites 114, 132, 133, 135, 137, and 143, Phase 4 Roadways, and Phase 5 Off-Site Properties) in Jersey City, New Jersey (the Site) where soil remediation has been completed or will be complete by the end of 2017.

A Capillary Rise Study was conducted to support the design of a permeable capillary break at the Site. The findings of this study were reported in the *Capillary Rise Study Final Report* (AECOM, 2017b). Based on the results of the Capillary Rise Study, it was determined that a 6-inch layer of open-grade stone (OGS) or a 2.8-foot layer of dense-grade aggregate (DGA)/DGA amended with FerroBlack®-H (A-DGA), would be an effective capillary break at the Site. A 40-millimeter (mm) high-density polyethylene (HDPE) impermeable liner was also established as an acceptable capillary break option in the *Remedial Action Work Plan (Soil) Rev. 2 Garfield Avenue Group Site 114, 132, 133, 134, 137, and 143, Jersey City, Hudson County, New Jerse*y (RAWP) (AECOM, 2012), which was conditionally approved by the New Jersey Department of Environmental Protection (NJDEP).

These are capillary break design options for use in areas within the Site where soil remediation has been completed or will be complete by the end of 2017 in accordance with PPG's obligation under the 1990 Administrative Consent Order (ACO) and the 2009 Judicial Consent Order (JCO), and consistent with the letter from Mr. Thomas Cozzi of the NJDEP to the former Site Administrator W. Michael McCabe, dated August 13, 2013 (*Updated Method to Determine Compliance with the Department's Chromium Policy Garfield Avenue Group - Sites 114, 132, 133, 135, 137, and 143*) (NJDEP, 2013) (Chrome Policy).

The site-specific criteria used to determine if a capillary break is required include evaluation of total chromium (Cr) concentrations in shallow and intermediate groundwater, hexavalent chromium (Cr^{+6}) concentrations in soil, the presence or absence of competent meadow mat (MM) (i.e., MM greater than 1 foot [ft]-thick), and the presence or absence of A-DGA. Based on an evaluation of these criteria, a capillary break is proposed in Interim Remedial Measures (IRM) area #1 (IRM #1), in portions of Phase 1B, Phase 3A, and in Forrest Street based on Site conditions and the site-specific criteria.

For the majority of the Site where a capillary break is required, the proposed capillary break design is a 6-inch layer of washed stone between geotextile placed above the capillary break design groundwater elevation of 13.2 ft in the North American Vertical Datum of 1988 (NAVD88) for the portion of the Site north of Carteret Avenue and 11.0 ft NAVD88 for the portion of the Site south of Carteret Avenue. The capillary break design groundwater elevations for the Site were determined based on groundwater elevation data collected from the Site from 2003 to 2016 and represent the highest groundwater elevations recorded within these two areas during this time period. Where a capillary break is required, DGA backfill material will be placed to raise the grade to the capillary break design groundwater elevation before placement of the stone capillary break. An HDPE liner is required adjacent to Garfield Avenue and within portions of Forrest Street where the final grade must be below the capillary break design groundwater elevation to accommodate the requirement to meet the surrounding grade.

1.0 Introduction

AECOM has prepared this report on behalf of PPG to present the proposed capillary break design for the portions of the Garfield Avenue (GA) Group of Sites (Sites 114, 132, 133, 135, 137, and 143, Phase 4 Roadways, and Phase 5 Off-Site Properties) in Jersey City, New Jersey (the Site) where soil remediation has been completed or will be complete by the end of 2017. Remediation of soil impacted with hexavalent chromium (Cr^{+6}) is being conducted at the Site ahead of groundwater remediation. Therefore, a capillary break is required in some areas within the Site to prevent the formation of surficial Cr^{+6} blooms (chromium blooms).

PPG proposed the use of an impermeable liner as a capillary break at the Site as part of the *Restoration Technical Execution Plan*, *Garfield Avenue Group, PPG Sites 114, 132, 133W, 137, and 143 – Jersey City, Hudson County, New Jersey* (AECOM, 2014a) and as presented in the *Remedial Action Work Plan (Soil) Rev. 2 Garfield Avenue Group Site 114, 132, 133, 134, 137, and 143, Jersey City, Hudson County, New Jerse*y (RAWP) (AECOM, 2012), which was conditionally approved by the New Jersey Department of Environmental Protection (NJDEP). Due to concerns raised by the Jersey City Redevelopment Agency (JCRA) and Hampshire, that an impermeable liner may be incompatible with future redevelopment plans for the Site, an evaluation was conducted to identify possible capillary break alternatives. Results of this evaluation were reported in the *Garfield Avenue Group Capillary Break Re-Evaluation* (AECOM, 2015). Subsequently, a Capillary Rise Study was conducted to support the design of a permeable capillary break for the prevention of surficial chromium blooms at the Site. The basis of the Capillary Rise Study was established in the *Capillary Break Statement of Work* (SOW) which was prepared, reviewed, and agreed to by all participants of the Capillary Break Working Group (Capillary Break Working Group, 2015). The technical approach used for evaluating permeable capillary break options as part of the Capillary Rise Study was described in the *Final Capillary Rise Technical Execution Plan* (AECOM, 2016a) (TEP). Interim report submittals describing the implementation of the study include the *Final Capillary Rise Study Test Plots As-Built Report* (AECOM, 2016b), the *Final Capillary Rise Study Data Collection, Processing, and Analysis Report* (AECOM, 2016c), and the C*apillary Rise Study Quarterly Data Reports* (AECOM, 2016d-g). Results of the Capillary Rise Study are presented in the *Capillary Rise Study Final Report* (Capillary Rise Study Report) (AECOM, 2017b). Finally, site-specific criteria used to determine the conceptual limits of capillary break were outlined in the letter from Mr. Thomas Cozzi of the NJDEP to the Site Administrator Ronald J. Riccio dated March 30, 2017 *(Capillary Break Determination for Portions of the Garfield Avenue Group Sites SRP PI Numbers: G000008791, G000008749, 025695, 246332, G000008753, and G000008759)* (NJDEP's Capillary Break Determination Letter) (NJDEP, 2017) (**Appendix A**).

Section 2.0 of this report presents the site-specific criteria, which determine the extent of the capillary break at the Site. **Section 3.0** presents the current conditions at the Site. **Section 4.0** presents the proposed capillary break extent for areas where soil remediation is complete at the Site (remediated areas). **Section 5.0** provides a discussion of the capillary break design options, the proposed capillary break design, and the controls that will be implemented to prevent re-contamination of remediated areas by adjacent areas not yet remediated. **Section 6.0** presents references used in this report.

2.0 Capillary Break Criteria and Conditions

This section provides a summary of the Capillary Rise Study, the site-specific criteria used to determine the extent of the capillary break at the Site, and conditions for use of a capillary break for the prevention of chromium blooms.

2.1 Capillary Rise Study

The mechanisms that govern surficial chromium blooms are related to Cr^{+6} concentrations in groundwater and contact of that groundwater with the exposed ground surface through capillary action. Capillary breaks create a discontinuity in water-filled pores that inhibit hydraulic connectivity across the break and thereby prevent potentially-impacted groundwater from reaching the surface through capillary action. A Capillary Rise Study was conducted to further investigate these mechanisms, which included both field tests and laboratory bench-scale tests (AECOM, 2017b). As part of the Capillary Rise Study the following aspects of chromium bloom formation associated with capillary action were evaluated in various backfill materials:

- The height of the capillary fringe in a range of backfill materials;
- The effectiveness of a capillary break layer at limiting the height of the capillary fringe; and
- The vertical rise of groundwater above the capillary fringe through capillary rise.

As part of the Capillary Rise Study, backfill materials evaluated for use as a potential capillary break included:

- Dense-grade aggregate (DGA);
- DGA amended with FerroBlack®-H (A-DGA);
- Sandy topsoil with high-organic matter content; and
- Washed ¾-inch open grade stone (OGS) between geotextile layers places between the water table and the ground surface.

Results of the Capillary Rise Study are discussed in more detail in **Section 5.1**.

2.2 Criteria for Determining Capillary Break Extent

The site-specific criteria presented herein apply to areas within the Site where soil remediation has been completed or will be complete by the end of 2017 in accordance with PPG's obligation under the 1990 Administrative Consent Order (ACO) and the 2009 Judicial Consent Order (JCO) and consistent with the letter from Mr. Thomas Cozzi of the NJDEP to the former Site Administrator W. Michael McCabe, dated August 13, 2013 (*Updated Method to Determine Compliance with the Department's Chromium Policy Garfield Avenue Group - Sites 114, 132, 133, 135, 137, and 143*) (NJDEP, 2013) (Chrome Policy). Under the ACO and the NJDEP's Chrome Policy, PPG is responsible for remediating visually-observed Chromate Chemical Production Waste (CCPW) and Cr^{+6} in soil associated with CCPW at concentrations exceeding the NJDEP interim Chromium Soil Cleanup Criteria (CrSCC) of 20 milligrams per kilogram (mg/kg) to the depth of meadow mat (MM) or a depth of 20 feet (ft) below ground surface (bgs), whichever depth is encountered first. This report does not address areas where remediation is not complete. However, the capillary break design does consider potential migration of CCPW-related impacts in groundwater and soil from non-remediated areas (i.e., areas where remediation will not be complete by the end of 2017) to adjacent remediated areas (or areas to be remediated by the end of 2017).

The data used to determine whether a capillary break is required include:

- Total chromium (Cr) concentrations in shallow groundwater (i.e., groundwater present above MM or above 20 ft bgs where MM is not present);
- Total Cr concentrations in intermediate groundwater (i.e., groundwater below the MM or 20 ft bgs to 40 ft bgs);
- Cr^{+6} concentrations in soil;
- Presence or absence of competent MM; and
- Presence or absence of backfill (i.e., DGA) amended with FerroBlack®-H at the same elevations as the MM.

Conditions for applying these site-specific criteria are also discussed in this section. These criteria were used to determine the conceptual limits of capillary break shown in the NJDEP's Capillary Break Determination Letter (NJDEP, 2017) (**Appendix A**).

2.2.1 Areas Not Requiring Capillary Break

Scenarios where a capillary break is not required based on the site-specific criteria are presented below. These scenarios represent situations where there is no risk of contaminated groundwater reaching the ground surface.

- Scenario 1
    - Competent MM is present;
    - Cr^{+6} concentrations in soil above MM are equal to or less than the CrSCC; and
    - Total Cr concentrations in shallow groundwater are equal to or less than the NJDEP Groundwater Quality Standard (GWQS) of 70 micrograms per liter (µg/L).
- Scenario 2
    - Competent MM is not present;
    - Cr^{+6} concentrations in soil are equal to or less than the CrSCC, regardless of depth; and
    - Total Cr concentrations in shallow and intermediate groundwater are equal to or less than the GWQS.
- Scenario 3
    - Competent MM is not present;
    - Cr^{+6} concentrations in soil are equal to or less than the CrSCC to 20 ft bgs;
    - Total Cr concentrations in shallow groundwater are equal to or less than the GWQS; and
    - Backfill amended with FerroBlack®-H is present at the similar elevation of MM serving as an engineering control.

2.2.2 Areas Requiring Capillary Break

In accordance with the ACO and the NJDEP Chrome Policy, a capillary break is required in some areas within the Site where remediation will be completed by the end of 2017 and where the site-specific criteria outlined in **Section 2.1.1** are not met. Scenarios where a capillary break is required, based on the site-specific criteria, are presented below.

- Scenario A
    - Total Cr concentrations in shallow groundwater area are greater than the GWQS.
- Scenario B
    - Total Cr concentrations in intermediate groundwater are greater than the GWQS; and
    - Competent MM is not present; or
    - No backfill amended with FerroBlack®-H present at the similar elevation of MM serving as an engineering control.
- Scenario C
    - Cr^{+6} concentrations in soil above competent MM are greater than the CrSCC; or
    - Cr^{+6} concentrations in soil are greater than the CrSCC, regardless of depth, and there is no backfill amended with FerroBlack®-H present at the similar elevation of MM serving as an engineering control.

2.3 Other Design Considerations

A Classification Exception Area (CEA) will be required until total Cr concentrations in groundwater meet the GWQS. The groundwater CEA will be proposed as part of the forthcoming groundwater Remedial Investigation Report (RIR) pursuant to New Jersey Administrative Code (N.J.A.C) 7:26E-4.9(a)7. The NJDEP will establish a groundwater CEA based on the actual and projected area and depth of the contaminant plume in accordance with the requirements of N.J.A.C. 7:26C-7.3. NJDEP will remove a groundwater CEA based upon groundwater data, collected pursuant to N.J.A.C. 7:26C-7.9(f), that indicate that the concentrations of total Cr in the groundwater are equal to or less than the GWQS. To demonstrate that concentrations of total Cr in groundwater satisfy the conditions of the site-specific criteria, total Cr concentrations must be equal to or less than the GWQS for two consecutive groundwater sampling events that are representative of the horizontal and vertical extent of a CEA, meeting the requirements of N.J.A.C. 7:26C-7.9(f). The time interval between groundwater sampling events shall be approved by the NJDEP.

A-DGA, serving as an engineering control for the soil remediation, is also contributing to the on-going remediation of groundwater and may serve as an engineering control for some areas of groundwater. In accordance with N.J.A.C. 7.26C-7.5, remedial action permits for soil and groundwater will be required since the Remedial Action will include the following:

- A deed notice or a declaration of environmental restrictions for soil;
- A groundwater CEA;
- A groundwater engineering control (FerroBlack®-H-amended DGA); and
- Biennial obligations for monitoring, maintenance, and evaluation of the remedial action.

Pursuant to N.J.A.C. 7.26E-5.7, the soil and groundwater remedial action permits will be applied for when soil and groundwater Remedial Action Reports (RARs) are submitted to the NJDEP, respectively. General conditions applicable to remedial action permits, including the requirement for biennial reporting, are included in N.J.A.C. 7.26C-7.7. Specific conditions applicable to soil and groundwater remedial action permits are included in N.J.A.C 7:26C-7.8 and -7.9, respectively. Financial assurance requirements will be applicable to the remedial action permit(s) that include(s) an engineering control, pursuant to N.J.A.C 7.26C-7.10. Conditions related to the transfer and modifications of a remedial action permit are provided in N.J.A.C. 7:26C-7.11 and -7.12, respectively.

Pursuant to N.J.A.C. 7.26C-7.13, a remedial action permit may be terminated by the NJDEP upon request of a permittee if the NJDEP finds that the Remedial Action:

- Meets all applicable remediation standards without the need for the remedial action permit; and
- Is protective of the public health and safety and of the environment without the presence of the remedial action permit.

Once a remedial action permit and CEA are no longer required by the NJDEP, the groundwater monitoring will be terminated.

3.0 Site Conditions

This section provides a summary the conditions at the Site, which are relevant to the capillary break site-specific criteria.

3.1 Soil Conditions

Soil remediation has been or will be conducted in accordance with PPG's obligation under the 1990 ACO and the 2009 JCO and consistent with the NJDEP's Chrome Policy in the following areas by the end of 2017, as depicted on **Figure 3-1**:

- Site 114 (Phases 1A, 1B, 1C, 2A, 2B-1, 2B-2, 2B-3, 2B-4, and Interim Remedial Measure [IRM #1]);
- Phase 3A (Sites 132 and 143);
- Phase 3B-North (Site 137A);
- Phase 3C (Sites 133E and 135 North, and Halladay Street South);
- Portion of the Forrest Street Properties (Phase 5 Off-Site Properties); and
- Al Smith Moving Property (Phase 5 Off-Site Properties).

In these remediated areas, the Cr^{+6} concentrations in soil meet (or will meet) the requirements for areas which do not need a capillary break. Documentation of compliance with the 1990 ACO and with the NJDEP's Chrome Policy will be provided in the separate RARs, which will be submitted at a later date.

Soil remediation will be conducted in Forrest Street in 2017, using the criteria presented in the Technical Memorandum entitled *Forrest Street and Forrest Street Properties – Proposed Terminal Excavation Elevations Submittal (Revision 1)* (AECOM, 2017d) and in the Technical Memorandum entitled *Forrest Street Properties – Supplemental Proposed Terminal Excavation Elevations Submittal* (AECOM, 2017f). CCPW will be removed via excavation. In Forrest Street, following remediation, the Cr^{+6} concentrations in soil due to CCPW-related impacts in groundwater will remain such that a capillary break will be required.

Note that, as presented in the *Technical Execution Plan (Revision 1) Forrest Street and Forrest Street Properties Soil Excavation, Jersey City, New Jersey* (Forrest Street and Forrest Street Properties TEP [Revision 1]) (AECOM, 2017c), engineering controls for areas beneath and adjacent to the Forrest Street buildings which will not be remediated in 2017 will be addressed in a forthcoming RAWP. These deferred areas are not included in this evaluation.

Adjacent GA Group areas where remediation of CCPW-related impacts will not be complete by the end of 2017 include:

- Carteret Avenue (Phase 4 Roadways);
- The Former Halsted Corporation property (Phase 5 Off-Site Properties);
- Garfield Avenue (Phase 4 Roadways);
- Halladay Street North (the portion of Halladay Street between Carteret Avenue and Forrest Street);

- Phase 3B South (Site 133W, a portion of Site 137, the former Fishbein property, the Ten West Apparel property) and the associated portion of Halladay Street South; and
- Portion of Forrest Street and Forrest Street Properties adjacent to and under the buildings.

For these areas an addendum(a) will be issued to this report documenting whether a capillary break is needed before the start of restoration in each area.

3.2 Groundwater Conditions

3.2.1 Shallow Groundwater

As depicted on **Figure 3-1**, total Cr concentrations in shallow groundwater are known or assumed to exceed the GWQS in the following areas:

- The northwest corner of Site 114;
- A portion of the southwest corner of Site 114;
- A portion of Site 199, approximately between Garfield Avenue and 300 ft to the east of Garfield Avenue;
- Beneath Carteret Avenue, between Garfield Avenue and Halladay Street;
- Beneath portions of Garfield Avenue, between Carteret Avenue and the New Jersey Transit Light Rail;
- A portion of Phase 3B-South; and
- A portion of Forrest Street and the Forrest Street Properties (within the areas of deferred remediation).

In remediated areas, total Cr concentrations in shallow groundwater range up to 184 µg/L in areas with A-DGA, while total Cr concentrations range up to 2,910 µg/L in areas without A-DGA (i.e., un-amended areas). In the areas not yet remediated, total Cr concentrations in shallow groundwater range up to 637,000 µg/L. **Table 3-1** provides a summary of total Cr analytical results for shallow groundwater from the last two consecutive sampling events (if more than one sampling event has occurred) at each monitoring well location.

Currently, there are no groundwater wells installed in the Al Smith Moving property. However, total Cr concentrations in shallow and intermediate groundwater within the Al Smith Moving property are estimated to be less than the GWQS based on data collected from wells on adjacent properties as shown on Figure 3-1 and 3-2. Therefore, no capillary break is required within the Al Smith Moving property.

In areas where a capillary break is needed due to impacts in shallow groundwater, the capillary break will extend over the area with GWQS exceedances to wells that have at least two consecutive rounds of groundwater sampling equal to or less than the GWQS. The iso-concentrations shown on **Figure 3-1** are interpolated based on the iso-concentration lines shown in the quarterly groundwater monitoring reports and updated with data generated since issuance of the previous report.

Appendix B provides laboratory analytical reports for the groundwater samples and **Appendix C** provides data validation reports not previously submitted as part of a separate document.

Sheet pile is present between the shallow groundwater within Site 114 and adjacent areas where shallow soils with CCPW-related impacts will remain beyond 2017 (i.e., Carteret Avenue, deferred portions of Forrest Street, deferred portions of the Forrest Street Properties, Halladay Street North, the Former Halsted Corporation Property, and within Phase 3B South). The extent of sheet pile present at the Site is shown in **Figures 3-1** through **5-1**. The sheet pile and A-DGA will minimize horizontal migration of total Cr from the areas not yet remediated to the shallow groundwater in remediated areas.

Groundwater is recharged from surface precipitation and vertical hydraulic gradients are generally downward at the Site for the majority of the year. The presence of the A-DGA and MM (described in detail in **Section 3.3**), combined with generally downward vertical hydraulic gradients, minimizes the potential for upward migration of Cr from the intermediate groundwater zone into the shallow groundwater zone.

3.2.2 Intermediate Groundwater

As depicted on **Figure 3-2**, total Cr concentrations in intermediate groundwater exceed the GWQS in the following areas:

- Site 114, with the exception of Phase 2A where a former manufactured gas plant was located;
- The portion of Site 199 approximately between Garfield Avenue and 300 ft to the east of Garfield Avenue;
- The northern half of Phase 3A;
- The northern half of Phase 3B North;
- A small portion of Phase 3C directly adjacent to Carteret Avenue;
- Carteret Avenue;
- The southwestern portion of the Forrest Street Properties and Forrest Street;
- Garfield Avenue adjacent to Site 114 and Site 143; and
- The southern two-thirds of the former Halsted Corporation property.

In the intermediate zone, the maximum total Cr concentration in groundwater from the last two consecutive sampling events is 5,430,000 µg/L in well MW6B located in the north central portion of Site 114. **Table 3-2** provides a summary of total Cr analytical results for intermediate groundwater from the last two consecutive sampling events (if more than one sampling event occurred) for each monitoring well location. There is a sharply declining concentration gradient at the plume fringes, where total Cr declines to less than the GWQS. Active remediation of groundwater is being considered for the intermediate zone chromium plume.

Groundwater is recharged from surface precipitation and vertical hydraulic gradients are generally downward at the Site for the majority of the year. The presence of the A-DGA in the shallow zone and MM (described in detail in **Section 3.3**), combined with downward vertical hydraulic gradients, will minimize the potential for upward migration of Cr from the intermediate zone into the shallow zone.

3.3 Meadow Mat Extent

MM, defined as an estuarine depositional unit predominately made up of peat (NJDEP, 2013), has been observed across the Site from approximately 6 ft North American Vertical Datum of 1988 (NAVD88) to 23 ft NAVD88, though not continuously. The extent of competent MM (i.e., greater than 1 ft-thick) is shown on **Figure 3-3** on a grid-by-grid basis (i.e., within a 30 by 30 ft area). Competent MM was determined present within a grid if MM was reported in a boring log at a minimum thickness of 1 ft or if it was confirmed that the MM layer was greater than 1 ft-thick during excavation and reported in the field notes. **Appendix D** lists boring or monitoring well locations where competent MM was confirmed during drilling and noted in the boring or monitoring well logs.

3.4 FerroBlack®-H Amendment Extent and Longevity Evaluation

3.4.1 FerroBlack®-H Extent

FerroBlack®-H has been applied to DGA backfill placed at the Site in various dosages ranging from 0.7% to 2.8% by weight. **Figure 3-3** presents the horizontal extent of A-DGA at the Site. **Table 3-3** lists the thickness of the A-DGA currently in place by phase.

3.4.2 FerroBlack®-H Longevity Evaluation

As described in **Section 5.3.2** and in the *Performance and Longevity Evaluation for Site Wide FerroBlack®-H-Amended Backfill, Garfield Avenue Group Chromium Sites, Jersey City, New Jersey (Revision 1)* (FerroBlack®-H Performance and Longevity Report [Revision 1]) (**Appendix E**), the longevity (in years) of the applied FerroBlack®-H was evaluated and the minimum required amendment thicknesses by phase were estimated. These estimates were developed with the assumption that the primary contributors to FerroBlack®-H exhaustion would be the presence of Cr^{+6} in the soil and groundwater, and dissolved oxygen (DO) present in the shallow and intermediate water-bearing zones. The results of the FerroBlack®-H evaluation are as follows:

- The most recent sampling data collected at the Site indicate that total Cr and Cr^{+6} concentrations in shallow groundwater are declining compared to pre-remedial conditions. It is anticipated that total Cr concentrations in shallow groundwater will continue to decline as Cr continues to precipitate out of the groundwater.
- pH conditions in groundwater following placement of the A-DGA are conducive to the conversion of Cr^{+6} to trivalent chromium (Cr^{+3}).
- Negative oxidation-reduction potential (ORP) and low DO (< 1 milligram/liter [mg/L]) conditions exist and are expected to be sustained in the amended shallow zone. Following placement of the A-DGA, ORP is negative (below 0 millivolts [mv]) and Cr^{+6} and total Cr concentrations are either less than the reporting limit of 10 µg/L or their concentrations are continuously declining.
- Where there are upward hydraulic gradients and the MM is absent, there is potential for the interaction of Cr^{+6} with the shallow amended soils, which would reduce the longevity of the applied amendment. However, groundwater gradients measured at the Site are generally downward, with brief periods of upward flow (for periods ranging from days to months).
- Areas where FerroBlack®-H has been applied to the backfill at the Site have sufficient quantity of the reductant present to sustain reducing conditions for a minimum of approximately 200 years.
- The minimum required amendment thickness to sustain reductive capacity for 30 years and 100 years ranges from 0.04 ft to 2.0 ft and from 0.1 ft to 6.7 ft, respectively.
- The reductive capacity of FerroBlack®-H is not the only factor that affects the longevity of the amendment. The presence of MM as a confining layer will prevent the upward migration of chromium-contaminated groundwater in areas of the Site where upward hydraulic gradients were measured.

3.5 Areas Not Yet Remediated Adjacent to Remediated Areas

3.5.1 Site 199

In Site 199, CCPW and concentrations of Cr^{+6} in soil that exceed the CrSCC are present in Site 199 adjacent to Site 114.

Total Cr concentrations in shallow groundwater range from 8.0 µg/L to 637,000 µg/L (**Table 3-1**). In intermediate groundwater, total Cr concentrations range from 3.7 µg/L to 392,000 µg/L (**Table 3-2**).

Shallow groundwater in Site 199 generally flows toward Site 114 until it reaches the sheet pile along Site 114 where it begins to flow toward the east. As seen in **Appendix F,** the top of the sheet pile between Site 114 and Site 199 ranges from 13.5 to 14.0 ft NAVD88, which is higher than the capillary break design groundwater elevation in this area, thus providing a horizontal barrier for shallow groundwater along this boundary even during high groundwater events (discussed in **Section 5.3**).

3.5.2 Garfield Avenue

Currently, there are no groundwater monitoring wells installed in Garfield Avenue. Shallow monitoring wells that are installed upgradient (west) of Garfield Avenue have total Cr concentrations that are less than the GWQS. Shallow wells installed downgradient (east) of Garfield Avenue also have total Cr concentrations that are less than the GWQS. However, downgradient, shallow monitoring wells located in Phase 1C were installed in amended backfill. Therefore, data from Phase 1C wells are not representative of groundwater conditions within Garfield Avenue adjacent to Phase 1C. Downgradient shallow monitoring wells located in IRM #1, Phase 1B, Carteret Avenue, and Phase 3A are installed in un-amended backfill. Therefore, data from these wells can be considered representative of groundwater conditions within Garfield Avenue. Based on the available data from upgradient and downgradient shallow monitoring wells, total Cr concentrations in shallow groundwater within Garfield Avenue are expected to be less than the GWQS in portions of Garfield Avenue. However, it is assumed that the total Cr concentrations in shallow groundwater within Garfield Avenue are greater than the GWQS from the NJ Transit Light Rail to Column 3B and from Columns 2A to 5A based on Cr^{+6} soil concentrations, which are generally higher in this area, and on the presence of visual CCPW in this area of Garfield Avenue.

Based on data collected from intermediate monitoring wells downgradient from Garfield Avenue, total Cr concentrations greater than the GWQS are expected in intermediate groundwater within Garfield Avenue (**Table 3-2** and **Figure 3-2**).

Shallow groundwater within Garfield Avenue generally flows toward Site 114 until it reaches the sheet pile along Site 114, where it begins to flow southward. However, the elevation of top of sheet pile along the majority of the length of sheet pile between Site 114 and Garfield Avenue is 10.0 ft NAVD88 (**Appendix F**), which is less than the capillary break design groundwater elevation for this area (discussed in **Section 5.3**). Therefore, in high groundwater events, shallow groundwater could migrate from Garfield Avenue to Site 114. A capillary break is already required along Garfield Avenue where there is a no A-DGA or competent MM. Along Phase 1C, the existing A-DGA will function as an engineering control during high groundwater events.

3.5.3 Carteret Avenue

As presented in the Technical Memorandum entitled *Carteret Avenue Terminal Excavation Elevation Submittal (Revision 1)* (AECOM, 2017a), Cr^{+6} concentrations in soil within Carteret Avenue range from non-detect to 13,900 mg/kg, and CCPW is present throughout Carteret Avenue, with the exception of a portion of Carteret Avenue situated between Halladay Street and Pacific Avenue.

Total Cr concentrations in shallow groundwater within Carteret Avenue range from 191 µg/L to 1,460 µg/L (**Table 3-1**). Total Cr concentrations in intermediate groundwater within Carteret Avenue range from 2,510 µg/L to 744,000 µg/L (**Table 3-2**).

Shallow groundwater in Carteret Avenue generally flows to the south. The elevation of the top of the sheet pile ranges from 9.8 to 14.3 ft NAVD88 between Site 114 and Carteret Avenue and from 9.0 to 13.0 ft NAVD88 between Phase 3A/Phase 3B/Phase 3C and Carteret Avenue (**Appendix F**). While the majority of the length of the sheet pile is higher than the capillary break design groundwater elevations in these areas and thus prevents migration of shallow groundwater from Carteret Avenue to remediated areas in most scenarios, portions of the sheet pile have a top of sheet pile elevation lower than the capillary break design groundwater elevation. Where the top of sheet pile along Carteret Avenue is lower than the capillary break design groundwater elevation, mitigation measures to prevent shallow groundwater from overtopping the sheet pile will be implemented as part of restoration. The proposed mitigation measures to address possible overtopping are discussed in the Technical Memorandum entitled *Mitigation Plan to Address Impacted Ponding Water at Northern Boundary of Halladay Street South and Phase 3B* (AECOM, 2017g). These mitigation measures will be maintained until soil remediation within Carteret Avenue is complete, including the replacement/relocation of the 96-inch combined sewer line in Carteret Avenue.

3.5.4 Halladay Street North

As presented in the Technical Memorandum entitled *Halladay Street North Terminal Excavation Elevation Submittal* (AECOM 2016h), Cr^{+6} concentrations in soil within Halladay Street North (i.e., the portion of Halladay Street between Carteret Avenue and Forrest Street) range from non-detect to 8,510 mg/kg. CCPW is present in Halladay Street North, but appears to be limited to the southern portion of the roadway pending additional investigation (AECOM, 2016h).

Total Cr concentrations in shallow groundwater are less than the GWQS and range from 23.5 µg/L to 28.1 µg/L (**Table 3-1**). The most recent total Cr concentration in intermediate groundwater measured in the southern portion of Halladay Street North is 52,000 µg/L (**Table 3-2**). However, total Cr concentrations in intermediate groundwater in the northern portion of Halladay Street North appear to be less than the GWQS based on data collected from adjacent wells in Site 114 (**Figure 3-2**).

The elevation of the top of the existing sheet pile between Site 114 Halladay Street North ranges from 9.1 to 12.9 ft NAVD88, which is lower than the capillary break design groundwater elevation for this area (discussed in **Section 5.3**). However, shallow groundwater in the southern portion of Halladay Street North flows eastward (i.e., from the remediated area to the area not yet remediated). In the northern portion of Halladay Street North, shallow groundwater generally flows southward. Therefore, no capillary break or additional engineering controls are required along Halladay Street North.

3.5.5 Forrest Street and Forrest Street Properties

As presented in the Forrest Street and Forrest Street Properties TEP (AECOM, 2017c), remediation of CCPW-related impacts beneath and adjacent to the Forrest Street buildings will be addressed in a forthcoming RAWP; therefore, these impacts will remain following remediation of adjacent areas to be complete at the end of 2017. However, shallow groundwater in Forrest Street and Forrest Street Properties flows northeastward/eastward (i.e., from the remediated area to the area not yet remediated), therefore no additional engineering controls are needed to protect the remediated areas adjacent to the un-remediated areas.

3.5.6 Phase 3B South

In Phase 3B South, Cr^{+6} concentrations in soil range from non-detect to 25,900 mg/kg (where the former Morris Canal was located) (AECOM, 2013, AECOM-2014b, AECOM-2014c). CCPW is interspersed throughout Phase 3B South.

Total Cr concentrations in shallow groundwater in Phase 3B South range from 7,770 µg/L to 8,750 µg/L (**Table 3-1**).

The elevation of the top of the existing sheet pile between Phase 3A and Phase 3B South ranges from 10.9 to 16.2 ft NAVD88; the minimum elevation of the top of the sheet pile in this area is lower than the capillary break design groundwater elevation (discussed in **Section 5.3**). However, shallow groundwater in the Phase 3B South area generally flows to the south (i.e., from the remediated areas to the area not yet remediated). Therefore, no capillary break or additional engineering controls are required adjacent to Phase 3B South.

4.0 Proposed Capillary Break Extent

This section discusses the proposed horizontal extent of a capillary break at the Site. Based on the site-specific criteria discussed in **Section 2.0**, a capillary break is required in IRM #1 and in portions of Phase 1B, Phase 3A, and Forrest Street as shown on **Figure 4-1**. Areas that do not require a capillary break are also shown in **Figure 4-1.** Each area that does not require a capillary break meets either Scenario 1, 2, or 3, described in **Section 2.2.1**.

4.1 IRM #1

A capillary break is required in IRM #1 where total Cr concentrations in shallow groundwater exceed the GWQS (**Figures 4-1** and **5-1**). A capillary break will be installed throughout IRM #1 where total Cr concentrations in intermediate groundwater exceed the GWQS (**Figure 4-1)**, because while MM has been observed throughout the IRM #1 area, the thickness of the layer was not confirmed in the field and A-DGA is only present in a small portion of the area (**Figure 3-3**). The capillary break will extend from Garfield Avenue to Row J, and from Column 1B to 9B (**Figures 4-1** and **5-1**).

4.2 Phase 1B

A capillary break is required in Phase 1B where total Cr concentrations in shallow groundwater exceed the GWQS (**Figures 4-1** and **5-1**). A capillary break will also extend to the west into portions of Phase 1B where total Cr concentrations in intermediate groundwater exceed the GWQS, because A-DGA is absent and the MM layer appears to either disappear or diminish in thickness near Garfield Avenue (**Figures 4-1** and **5-1**). The limits of the capillary break will extend to groundwater monitoring well locations with total Cr concentrations in shallow groundwater equal to or less than the GWQS for two consecutive sampling events (i.e., 114-P1B-MW101S, 114-P1B-MW103S, 114-MC-MW101S, 114-MC-MW102S, and 114-P1B-MW104S), and from Garfield Avenue to Row A, from Carteret Avenue to Column 5A, and from Garfield Avenue to Row B from Column 4A to Column 0.

4.3 Phase 3A

A capillary break is required in the northwestern portion of Phase 3A where total Cr concentrations in intermediate groundwater exceed the GWQS, because competent MM or A-DGA is not present. The limits of the capillary break include portions of Rows A’ through C; this extends from Column 17A to the intermediate clean well 132-P3A-MW102I in Column 26A (**Figure 4-1** and **Figure 5-1**).

4.4 Forrest Street

A capillary break is required in portions of Forrest Street (**Figures 4-1** and **5-1**) where remediation of CCPW-related impacts in soil will be complete by the end of 2017 and where total Cr concentrations in shallow groundwater exceed the GWQS. A capillary break will be required in portions of Forrest Street (**Figures 4-1** and **5-1**) where remediation of CCPW-related impacts in soil will be complete by the end of 2017, but where Cr^{+6} concentrations in soil are greater than the CrSCC due to CCPW-related impacts in groundwater. The limits of the capillary break (**Figure 4-1** and **Figure 5-1**) will extend from Row W along the southern boundary of Forrest Street (along Site 114), to the east to Row CC, and to the northern extent of 2017 soil remediation in Forrest Street. The deferred portion of Forrest Street is not evaluated here; it will be addressed in a forthcoming RAWP.

5.0 Capillary Break Design

This section provides a summary of the Capillary Rise Study and capillary break design options evaluated for installation at the Site.

5.1 Evaluation of Design Options

The allowable capillary break design options for installation at the Site include a 6-inch layer of washed OGS, a 2.8-foot layer of A-DGA/DGA, and a 40-millimeter (mm) high density polyethylene (HDPE) liner.

5.1.1 Washed Open Grade Stone Capillary Break

The approved Capillary Rise Study Final Report (AECOM, 2017b) concluded that a 6-inch layer of washed OGS placed between layers of geotextile (10 ounces per square yard [oz/sy]) is an effective capillary break when placed above the capillary break design groundwater elevation discussed in **Section 5.3**. The OGS evaluated as part of the Capillary Rise Study met the requirements of the American Association of State Highway and Transportation Officials (ASHHTO) #57 specification. The OGS was washed so that less than 5% of the material was smaller than 3/8-inch. This type of capillary break will be the most commonly used capillary break at the Site (where required) due to the ease of installation and maintenance, combined with its low profile in the soil column.

5.1.2 A-DGA/DGA Capillary Break

The approved Capillary Rise Study Final Report (AECOM, 2017b) also concluded that a 2.8-ft layer of A-DGA/DGA placed above the capillary break design groundwater elevation discussed in **Section 5.3** would function as a capillary break. DGA used to construct a capillary break at the Site must have the same or coarser particle size distribution than the DGA used in the Capillary Rise Study. **Table 5-1** presents the particle size distribution as determined by American Society for Testing and Materials (ASTM) Method D422 for the DGA material and the A-DGA material evaluated as part of the Capillary Rise Study.

There are currently no locations at the Site where a DGA capillary break is proposed because a 2.8-ft-thickness cannot be accommodated between the capillary break design groundwater elevation and street grade, both existing and proposed.

In an email from Benjamin Delisle of JCRA to the Site Administrator Project Manager James D. Ray, dated March 8, 2017 (*Restoration of GA Sites, Basis of Design*) (JCRA, 2017) (**Appendix G**), JCRA, the City of Jersey City, and Hampshire issued comments and guidelines for the restoration of the GA Group Sites. In their March 8, 2017 email, JCRA, the City of Jersey City, and Hampshire stated that their preferred capillary break material is DGA. The elevation of the top of a capillary break consisting of 2.8-foot layer of DGA placed above the capillary break design groundwater elevation of 13.2 ft NAVD88 north of Carteret Avenue would bring the elevation to approximately 16.0 ft NAVD88, which would be incompatible with the adjacent roadways (existing grade of existing roadways is approximately 10 to 12 ft NAVD88). Similarly, a capillary break consisting of a 2.8-foot layer of DGA south of Carteret Avenue is not compatible with adjacent roadways as the elevation of the top of such a capillary break would be approximately 13.8 ft NAVD88. Therefore, DGA is not proposed as a capillary break material at the Site.

5.1.3 HDPE Liner Capillary Break

For areas where a OGS or DGA/A-DGA capillary break cannot be placed due to space restrictions, the RAWP (AECOM, 2012), which was conditionally approved by the NJDEP, specified the use of a capillary break consisting of a 40-mm HDPE liner placed between two 10-oz/sy non-woven geotextile layers. This type of capillary break will be used in areas where a capillary break is required and the final restoration grade required to tie into existing street grade is lower than the grade required to accommodate a capillary break consisting of OSG or DGA/A-DGA (i.e., at or above the capillary break design groundwater elevation). If the HDPE liner capillary break is compromised PPG, will replace or repair the liner until the NJDEP determines that a capillary break is no longer required in the applicable area, based on improved Site conditions. If re-development activities require modifications to the liner, and site conditions have changed such that one of the other capillary break options is acceptable, the HDPE liner may be replaced with one of the other approved options.

5.1.4 HDPE Liner Sloping

The HDPE capillary break usage will be limited to areas where a permeable capillary break cannot be placed between the capillary break design groundwater elevation and the final surface grades. In areas where the HDPE capillary break must be used, the HDPE liner will generally be placed 1 to 2 ft below the final grade surface. The liner will follow the slopes of the final grade surface until the final grade is high enough to accommodate a permeable capillary break. Once that elevation has been reached, the HDPE capillary break will be overlapped with the permeable capillary break by 10 ft.

5.2 Capillary Break Design Groundwater Elevation

A capillary break design groundwater elevation of 13.2 ft NAVD88 was established for the portion of the Site north of Carteret Avenue where a capillary break is required; this elevation represents the highest groundwater elevation recorded north of Carteret Avenue within Site 114 from 2003 to 2016 (recorded at well MW3A) (**Appendix H**). Where a capillary break is required north of Carteret Avenue, a permeable capillary break must be placed above 13.2 ft NAVD88 per the NJDEP's Capillary Break Determination Letter (NJDEP, 2017).

A capillary break design groundwater elevation of 11.0 ft NAVD88 was established for the portion of the Site south of Carteret Avenue where soil remediation is complete and where a capillary break is required; this elevation represents the highest groundwater elevation recorded in Carteret Avenue, Phase 3A, and Phase 3B North from 2003 to 2016 (recorded at MW4A) (**Appendix H**).

A capillary break design groundwater elevation of 11.4 ft NAVD88 was established for Forrest Street and the Forrest Street Properties where soil remediation will be complete by the end of 2017 and where a capillary break is required; this elevation represents the highest groundwater elevation recorded in Forrest Street and Forrest Street Properties from 2003 to 2016 (recorded at monitoring well MW3S) (**Appendix H**).

5.3 Engineering Controls to Prevent Re-contamination by Intermediate Groundwater

Under Scenario 1 and 3 described in **Section 2.2.1**, a capillary break is not needed because either MM or A-DGA is present to act as an engineering control to prevent re-contamination of the shallow groundwater by intermediate groundwater at concentrations greater than the GWQS.

The naturally existing MM functions as a chemical barrier by creating a reducing environment, which is not conducive to the formation of Cr^{+6}. Therefore, a competent MM layer acts as an engineering control. Additionally, a competent MM layer functions as a physical barrier between intermediate groundwater and overburden material, due to its very low permeability. Where present, MM has been used to demarcate the bottom of excavation during soil remediation since a competent MM layer acts as an engineering control.

FerroBlack®-H is a reducing agent that causes the soluble and mobile form of chromium, Cr^{+6}, to be reduced to the insoluble and immobile form, Cr^{+3}. When mixed with backfill placed in the excavation, FerroBlack®-H has been used as a groundwater engineering control in some remediated areas within the Site to prevent impacted groundwater from re-contaminating overburden soil and clean backfill material. The amended backfill (i.e., A-DGA) is placed at the bottom of the excavation, where it performs the same function as MM by reducing Cr^{+6} in the intermediate groundwater before it can re-contaminate the shallow groundwater.

5.3.1 Engineering Control Conditions

To satisfy the NJDEP requirements, the FerroBlack®-H amended backfill must be placed at an elevation where MM would be expected but is not present, to provide a continuous barrier across an area. The means for demonstrating the effectiveness of the FerroBlack®-H amended backfill as an engineering control are described in **Section 5.3.2**.

The competent MM layer and a minimum thickness of FerroBlack®-H amended backfill must remain intact as an engineering control until concentrations of total Cr in shallow and intermediate groundwater meet the GWQS. **Table 5-2** presents the minimum A-DGA thickness by phase required to maintain reductive capacity for 30 years and for 100 years as determined in the FerroBlack®-H Performance and Longevity Report (Revision 1) (Attachment C of **Appendix E**). Note that NJDEP requires a minimum A-DGA thickness of 1 ft to ensure the appropriate coverage.

5.3.2 Means for Demonstrating Effectiveness

To demonstrate that the A-DGA remains effective as an engineering control, biennial monitoring of shallow and intermediate groundwater is proposed and will include analyses of the following parameters:

- Cr^{+6}
- Total Cr
- pH
- ORP
- DO
- Sulfide

- Ferrous iron

The monitoring parameters, frequency, and schedule for the biennial groundwater sampling will be included as part of the future remedial action permit application. Total Cr concentrations and Cr^{+6} concentrations less than the GWQS would be a direct indication that the engineering control is working as designed. Additionally, analysis of geochemical data (i.e., pH, ORP, DO, sulfide, and ferrous iron) help determine if the groundwater environment is a reducing one (i.e., is electron rich) in which residual Cr^{+6} is reduced to Cr^{+3}. As stated in **Section 2.3**, biennial groundwater monitoring will be terminated once the NJDEP determines that a remedial action permit and CEA are no longer required.

An evaluation was conducted to assess the predicted performance and longevity of the A-DGA backfill at the Site, which consisted of the following:

- An assessment of the longevity (i.e., maximum number of years FerroBlack®-H can maintain reducing conditions) at the Site based on the stoichiometric demand from various electron acceptors (e.g., flux of existing Cr^{+6} in groundwater, flux of DO in the shallow and intermediate zone groundwater, and flux of DO in precipitation). The flux of these electron acceptors were calculated based on the hydraulic conductivities, hydraulic gradient (upward or downward), concentration of Cr^{+6} in groundwater, and concentration of DO; and
- An assessment of the minimum thickness of the FerroBlack®-H needed to sustain reducing conditions for 30 years and 100 years and then comparing it to the existing thickness of the amended backfill to evaluate sufficiency of the engineering control.

Details and results of this evaluation were presented in the (FerroBlack®-H Performance and Longevity Report Revision 1) (**Appendix E**). A summary of the findings from this evaluation are also presented in **Section 3.4**.

5.4 Final Design Recommendation

The proposed extent of each type of capillary break is shown on **Figure 5-1**. The areas for each type of capillary break may be modified based on development of final site grading. The capillary break will be installed at the capillary break design groundwater elevations presented in **Section 5.2**.

Biennial monitoring of shallow and intermediate groundwater will be conducted to demonstrate that the engineering controls are effective until shallow and intermediate groundwater remediation is complete. When monitoring indicates that areas have met the requirements for not needing a capillary break, the limits of the capillary break and required engineering controls laid out in the relevant permits and deed notices will be modified to remove the capillary break requirements.

6.0 References

AECOM, 2012. *Remedial Action Work Plan (Soil) Rev. 2 Garfield Avenue Group Site 114, 132, 133, 134, 137, and 143, Jersey City, Hudson County, New Jerse*y. April 2012.

AECOM, 2013. Technical Memorandum to David Doyle, Prabal Amin, and Brian McPeak, Subject: *Re: PPG Target Excavation Depths in Phase 3B & 3C*. August 19, 2013.

AECOM, 2014a. *Restoration Technical Execution Plan*, *Garfield Avenue Group, PPG Sites 114, 132, 133W, 137, and 143 – Jersey City, Hudson County, New Jersey.* October 2014.

AECOM, 2014b. Technical Memorandum to David Doyle, Prabal Amin, Laura Amend-Babcock, and Brian McPeak, Subject: *Re: PPG Supplement Target Excavation Elevations in Phase 3B & 3C*. January 22, 2014.

AECOM, 2014c. Technical Memorandum to David Doyle, Prabal Amin, Laura Amend-Babcock, and Brian McPeak, Subject: *Re: PPG Supplement Target Excavation Elevations in Phase 3B South*. July 17, 2014.

AECOM, 2015. Technical Memorandum to Brian McPeak, Subject: *Re: Garfield Avenue Group Capillary Break Re-Evaluation*. March 13, 2017.

AECOM, 2016a. *Final Capillary Rise Technical Execution Plan*. Document No. GAG-034. February 2016.

AECOM, 2016b. *Final Capillary Rise Study Test Plots As-Built Report*. Document No. GAG-036A. May 6, 2016.

AECOM, 2016c. *Final Capillary Rise Study Data Collection, Processing, and Analysis Report.* Document No. GAG-036B. May 6, 2016.

AECOM, 2016d. *Capillary Rise Study 1st Quarterly Data Report (Q4 2015)*. Document No. GAG-036D. May 6, 2016.

AECOM, 2016e. *Capillary Rise Study 2nd Quarterly Data Report (Q1 2016)*. Document No. GAG-036E. July, 2016.

AECOM, 2016f. *Capillary Rise Study 3rd Quarterly Data Report (April – June 2016)*. Document No. GAG-036F. August, 2016.

AECOM, 2016g. *Capillary Rise Study 4th Quarterly Data Report (July 1 – October 14, 2016)*. Document No. GAG-036G. November, 2016.

AECOM, 2016h. Technical Memorandum to Tom Cozzi, Subject: Re: *Halladay Street North Terminal Excavation Elevation Submittal*. November 22, 2016.

AECOM, 2017a. Technical Memorandum to Tom Cozzi, Subject: Re: *Carteret Avenue Terminal Excavation Elevation Submittal (Revision 1)*. February 17, 2017.

AECOM, 2017b. *Capillary Rise Study Final Report.* Document No. GAG-036H. March 2017.

AECOM, 2017c. *Technical Execution Plan (Revision 1), Forrest Street and Forrest Street Properties Soil Excavation, Jersey City, New Jersey*. March 2017.

AECOM, 2017d. Technical Memorandum to Tom Cozzi, Subject: Re: *Forrest Street and Forrest Street Properties - Proposed Terminal Excavation Elevation Submittal (Revision 1)*. March 30, 2017.

AECOM, 2017e. Technical Memorandum to Tom Cozzi, Subject: Re: *Al Smith Moving Property – Proposed Terminal Excavation Elevations Submittal (Revision 1)*. March 31, 2017.

AECOM, 2017f. Technical Memorandum: *Forrest Street Properties – Supplemental Proposed Terminal Excavation Elevations Submittal.* April 14, 2017.

AECOM, 2017g. Technical Memorandum: *Mitigation Plan to Address Impacted Ponding Water at Northern Boundary of Halladay Street South and Phase 3B.* June 19, 2017.

Capillary Break Working Group, 2015. Capillary Break Statement of Work. May 19, 2015.

JCRA, 2017. Letter from Ben Delisle of JCRA to James D. Ray, Subject: *Re: Restoration of GA Sites, Basis of Design*. March 8, 2017.

NJDEP, 2013. Letter from Tom Cozzi of NJDEP to W. Michael McCabe, Subject: *Re: Updated Method to Determine Compliance with the Department's Chromium Policy, Garfield Avenue Group – Sites 114, 132, 133, 135, 137, and 143, Jersey City, NJ*. August 13, 2013.

NJDEP, 2017. Letter from Mr. Thomas Cozzi to Ronald J. Riccio, Esq., Subject: *Re: Capillary Break Determination for Portions of the Garfield Avenue Group Sites SRP PI Numbers: G000008791, G000008749, 025695, 246332, G000008753, and G000008759.* March 30, 2017.

Tables

Table 3-1
Summary of Total Chromium Analytical Results - Shallow Groundwater
Capillary Break Design - Final Report (Revision 2)
PPG, Jersey City, New Jersey

					Analyte	CHROMIUM	
					CAS RN	7440-47-3	
					GWQS	70	
					Units	ug/L	
Well ID	**Sample ID**	**Sample Type**	**Sample Date**	**Fraction**	**Lab SDG**	**Result**	**Qualifier**
114-MC-MW101S	114-MC-MW101S-20160314	N	3/14/2016	T	JC16175	1.0	J
114-MC-MW101S	114-MC-MW101S-20160314X	FD	3/14/2016	T	JC16175	5.9	J
114-MC-MW101S	114-MC-MW101S-20160622	N	6/22/2016	T	JC22758	14.3	J
114-MC-MW102S	114-MC-MW102S-20160314	N	3/14/2016	T	JC16175	4.9	J
114-MC-MW102S	114-MC-MW102S-20160624	N	6/24/2016	T	JC22939	5.8	J
114-MW20A	G000005480-2/27/2014-PPG-114-MW-20A	N	2/27/2014	T	JB60752	63.6	
114-MW20A	114-MW20A-10.5-20151001	N	10/1/2015	T	JC5237A	23.5	
114-MW20A	114-MW20A-12.5-20151001	N	10/1/2015	T	JC5237A	28.1	
114-MW22A	114-MW22A-GA01-10.0	N	6/15/2011	T	460277151	< 4.1	U
114-MW22A	114-MW22A-GA01-10.0X	FD	6/15/2011	T	460277151	< 4.1	U
114-MW22A	114-MW22A-GA01-16.0	N	6/15/2011	T	460277151	4.2	J
114-MW22A	G000005480-4/1/2014-PPG-114-MW-22A	N	4/1/2014	T	JB63510	< 0.92	
114-MW24A	114-MW24A-20150722	N	7/22/2015	T	JB99718A	37.2	
114-MW24A	114-MW24A-20170405	N	4/5/2017	T	JC40469	15.4	J
114-MW25A	114-MW25A-20150720	N	7/20/2015	T	JB99503A	**202**	
114-MW25A	114-MW25A-20160926	N	9/26/2016	T	JC28410	**165**	
114-MW26A	114-MW26A-09252013	N	9/25/2013	T	JB48429	2.4	J
114-MW26A	114-MW26A-09252013X	FD	9/25/2013	T	JB48429	2.4	J
114-MW26A	114-MW26A-20150721	N	7/21/2015	T	JB99605A	1.2	J
114-MW27A	G000005480-4/2/2014-PPG-114-MW-27A	N	4/2/2014	T	JB63599	< 0.92	
114-MW27A	114-MW27A-20150720	N	7/20/2015	T	JB99503A	< 0.77	U
114-MW28A	114-MW28A-09252013	N	9/25/2013	T	JB48429	1.3	J
114-MW28A	114-MW28A-20150721	N	7/21/2015	T	JB99605A	1.0	J
114-MW30A	114-MW30A-09252013	N	9/25/2013	T	JB48429	1.8	J
114-MW30A	114-MW30A-20150721	N	7/21/2015	T	JB99605A	1.9	J
114-MW36A	114-MW36A-20150721	N	7/21/2015	T	JB99605A	50.1	
114-MW36A	114-MW36A-20160926-8.5	N	9/26/2016	T	JC28410	< 0.81	UB
114-MW36A	114-MW36A-20160926-13.5	N	9/26/2016	T	JC28410	< 0.81	UB
114-MW38A	114-MW38A-20150723	N	7/23/2015	T	JB99807A	6.5	J
114-MW38A	114-MW38A-20170331	N	3/31/2017	T	JC40140	8.0	J
114-P1A-MW101S	114-P1A-MW101S-20160617	N	6/17/2016	T	JC22504	5.0	J
114-P1A-MW101S	114-P1A-MW101S-20160916	N	9/16/2016	T	JC27812	< 0.81	U
114-P1B-MW101S	114-P1B-MW101S-20160314	N	3/14/2016	T	JC16175	54.4	
114-P1B-MW101S	114-P1B-MW101S-20160621	N	6/21/2016	T	JC22642	39.2	J
114-P1B-MW102S	114-P1B-MW102S-20160916	N	9/16/2016	T	JC27812	**366**	
114-P1B-MW102S	114-P1B-MW102S-20170412	N	4/12/2017	T	JC41030	**184**	
114-P1B-MW103S	114-P1B-MW103S-20160318	N	3/18/2016	T	JC16549	4.7	J
114-P1B-MW103S	114-P1B-MW103S-20160622	N	6/22/2016	T	JC22758	9.5	JB
114-P1B-MW104S	114-P1B-MW104S-20160322	N	3/22/2016	T	JC16738	20.3	J
114-P1B-MW104S	114-P1B-MW104S-20160621	N	6/21/2016	T	JC22642	56.4	
114-P1C-MW101S	114-P1C-MW101S-20160316	N	3/16/2016	T	JC16336	30.0	J
114-P1C-MW101S	114-P1C-MW101S-20160620	N	6/20/2016	T	JC22555	32.2	
114-P1C-MW102S	114-P1C-MW102S-20170403	N	4/3/2017	T	JC40254	5.3	J
114-P1C-MW102S	114-P1C-MW102S-20170403X	FD	4/3/2017	T	JC40254	4.5	J
114-P1C-MW102S	114-P1C-MW102S-20170523	N	5/23/2017	T	JC43922	5.9	J
114-P1C-MW103S	114-P1C-MW103S-20170404	N	4/4/2017	T	JC40335	16.5	
114-P1C-MW103S	114-P1C-MW103S-20170523	N	5/23/2017	T	JC43922	4.0	J
114-P1C-MW104S	114-P1C-MW104S-20170404	N	4/4/2017	T	JC40335	2.8	J
114-P1C-MW104S	114-P1C-MW104S-20170523	N	5/23/2017	T	JC43922	0.90	J
114-P2A-MW101S	114-P2A-MW101S-20160914	N	9/14/2016	T	JC27595	4.1	J
114-P2A-MW101S	114-P2A-MW101S-20160914X	FD	9/14/2016	T	JC27595	3.7	J
114-P2A-MW101S	114-P2A-MW101S-20161212	N	12/12/2016	T	JC33522	3.8	J
114-P2A-MW101S	114-P2A-MW101S-20161212X	FD	12/12/2016	T	JC33522	< 0.81	U
114-P2A-MW102S	114-P2A-MW102S-20160914	N	9/14/2016	T	JC27595	5.0	J
114-P2A-MW102S	114-P2A-MW102S-20160927-13.5	N	9/27/2016	T	JC28464	5.1	J
114-P2A-MW102S	114-P2A-MW102S-20160927-18.5	N	9/27/2016	T	JC28464	7.0	J
114-P2A-MW102S	114-P2A-MW102S-20161212	N	12/12/2016	T	JC33522	8.4	J
114-P2A-MW103S	114-P2A-MW103S-20160915	N	9/15/2016	T	JC27716	26.8	
114-P2A-MW103S	114-P2A-MW103S-20161213	N	12/13/2016	T	JC33573	< 4.1	U
114-P2A-MW104S	114-P2A-MW104S-20160915	N	9/15/2016	T	JC27716	< 0.81	U
114-P2A-MW104S	114-P2A-MW104S-20161214	N	12/14/2016	T	JC33691	5.1	JB
114-P2B1-MW101S	114-P2B1-MW101S-20160315	N	3/15/2016	T	JC16239	4.1	J
114-P2B1-MW101S	114-P2B1-MW101S-20160620	N	6/20/2016	T	JC22555	37.5	
114-P2B1-MW102S	114-P2B1-MW102S-20170412	N	4/12/2017	T	JC41030	2.9	J
114-P2B1-MW102S	114-P2B1-MW102S-20170524	N	5/24/2017	T	JC44024	0.90	J

Table 3-1
Summary of Total Chromium Analytical Results - Shallow Groundwater
Capillary Break Design - Final Report (Revision 2)
PPG, Jersey City, New Jersey

					Analyte	**CHROMIUM**	
					CAS RN	**7440-47-3**	
					GWQS	**70**	
					Units	**ug/L**	
Well ID	**Sample ID**	**Sample Type**	**Sample Date**	**Fraction**	**Lab SDG**	**Result**	**Qualifier**
114-P2B1-MW103S	114-P2B1-MW103S-20160316	N	3/16/2016	T	JC16336	43.2	J
114-P2B1-MW103S	114-P2B1-MW103S-20160623	N	6/23/2016	T	JC22854	43.9	
114-P2B2-MW101S	114-P2B2-MW101S-20160315	N	3/15/2016	T	JC16239	10.9	
114-P2B2-MW101S	114-P2B2-MW101S-20160620	N	6/20/2016	T	JC22555	19.3	
114-P2B3-MW101S	114-P2B3-MW101S-20160315	N	3/15/2016	T	JC16239	4.7	J
114-P2B3-MW101S	114-P2B3-MW101S-20160622	N	6/22/2016	T	JC22758	9.5	JB
114-P2B4-MW101S	114-P2B4-MW101S-20160316	N	3/16/2016	T	JC16336	16.4	J
114-P2B4-MW101S	114-P2B4-MW101S-20160621	N	6/21/2016	T	JC22642	29.3	J
114-P2B4-MW102S	114-P2B4-MW102S-20160322	N	3/22/2016	T	JC16738	45.3	J
114-P2B4-MW102S	114-P2B4-MW102S-20160621	N	6/21/2016	T	JC22642	18.1	J
114-P2B4-MW103S	114-P2B4-MW103S-20160316	N	3/16/2016	T	JC16336	20.0	J
114-P2B4-MW103S	114-P2B4-MW103S-20160622	N	6/22/2016	T	JC22758	16.1	JB
132-MW2A	132-MW2A-GA01-10.5	N	6/17/2011	T	460278051	< 4.1	U
132-MW2A	132-MW2A-GA01-15.5	N	6/17/2011	T	460278051	4.1	J
132-MW2A	G000005480-4/3/2014-PPG-132-MW-2A	N	4/3/2014	T	JB63769	< 0.92	
132-P3A-MW102S	132-P3A-MW102S-20160617	N	6/17/2016	T	JC22504	27.2	
132-P3A-MW102S	132-P3A-MW102S-20170313	N	3/13/2017	T	JC38888	2.4	J
132-P3A-MW103S	132-P3A-MW103S-20160318	N	3/18/2016	T	JC16549	6.7	J
132-P3A-MW103S	132-P3A-MW103S-20160616	N	6/16/2016	T	JC22356	6.6	J
132-P3A-MW104S	132-P3A-MW104S-20160318	N	3/18/2016	T	JC16549	3.5	J
132-P3A-MW104S	132-P3A-MW104S-20160616	N	6/16/2016	T	JC22356	1.7	J
132-P3A-MW4	132-P3A-MW4-20151215-13.0	N	12/15/2015	T	JC10722	**8750**	**J**
132-P3A-MW4	132-P3A-MW4-20151215-17.0	N	12/15/2015	T	JC10722	**7770**	**J**
133-MW2A	PPG133-MW2AJ61161-19	N	5/16/2007	T	J61161	< 10	UJ
133-MW2A	133-MW2A-GA01-5.5	N	6/20/2011	T	460278911	7.0	
133-MW2A	133-MW2A-GA01-10.5	N	6/20/2011	T	460278911	8.4	
133-MW6A	133-MW6A-20151217-9.0	N	12/17/2015	T	JC10941	46.3	
133-MW6A	133-MW6A-20151217-12.0	N	12/17/2015	T	JC10941	**263**	
133-P3C-MW101S	133-P3C-MW101S-20160913	N	9/13/2016	T	JC27486	3.2	J
133-P3C-MW101S	133-P3C-MW101S-20160913X	FD	9/13/2016	T	JC27486	3.3	J
133-P3C-MW101S	133-P3C-MW101S-20161216	N	12/16/2016	T	JC33887	< 0.81	UB
133-P3C-MW102S	133-P3C-MW102S-20160913	N	9/13/2016	T	JC27486	10.6	
133-P3C-MW102S	133-P3C-MW102S-20161216	N	12/16/2016	T	JC33887	4.4	JB
133-P3C-MW102S	133-P3C-MW102S-20161216X	FD	12/16/2016	T	JC33887	4.7	JB
135-MW1A	135-MW1A-GA01-7.0	N	6/27/2011	T	460281431	19.1	J
135-MW1A	135-MW1A-GA01-13.0	N	6/27/2011	T	460281431	< 4.1	U
135-MW1A	G000005480-2/28/2014-PPG-135-MW1A	N	2/28/2014	T	JB60865	< 0.92	U
135-MW2A	135-MW2A-8.5	N	10/6/2015	T	JC5499	5.1	J
135-MW2A	135-MW2A-12.5	N	10/6/2015	T	JC5499	2.9	J
135-MW2A	135-MW2A-14.7	N	10/6/2015	T	JC5499	5.5	J
135-MW2A	135-MW2A-20170316	N	3/16/2017	T	JC39023	1.5	J
137-P3B-MW101S	137-P3B-MW101S-20170316	N	3/16/2017	T	JC39023	< 8.1	U
137-P3B-MW101S	137-P3B-MW101S-20170316X	FD	3/16/2017	T	JC39023	< 8.1	UJ
137-P3B-MW101S	137-P3B-MW101S-20170525	N	5/25/2017	T	JC44131	41.7	
137-P3B-MW101S	137-P3B-MW101S-20170525X	FD	5/25/2017	T	JC44131	41.2	
137-P3B-MW102S	137-P3B-MW102S-20160615	N	6/15/2016	T	JC22273	< 16	UJ
137-P3B-MW102S	137-P3B-MW102S-20160615X	FD	6/15/2016	T	JC22273	< 16	UJ
137-P3B-MW102S	137-P3B-MW102S-20170317	N	3/17/2017	T	JC39113	< 0.81	U
143-P3A-MW101S	143-P3A-MW101S-20160318	N	3/18/2016	T	JC16549	3.0	J
143-P3A-MW101S	143-P3A-MW101S-20160318X	FD	3/18/2016	T	JC16549	6.6	J
143-P3A-MW101S	143-P3A-MW101S-20160620	N	6/20/2016	T	JC22555	20.0	
GPS-EW2S	GPS-EW2S-060316	N	6/3/2016	T	JC21504	3.4	J
GPS-EW2S	GPS-EW2S-083016	N	8/30/2016	T	JC26754	1.4	J
GPS-IW1S	114-ABPT-IW1S-010615	N	1/6/2015	T	JB85757A	**1640**	**J**
GPS-IW1S	114-ABPT-IW1S-040715	N	4/7/2015	T	JB91794	**220**	
GPS-IW2S	114-ABPT-IW2S-010615	N	1/6/2015	T	JB85757A	**569**	**J**
GPS-IW2S	114-ABPT-IW2S-040715	N	4/7/2015	T	JB91794	**313**	
GPS-MW1S	GPS-MW1S-060316	N	6/3/2016	T	JC21504	**839**	
GPS-MW1S	GPS-MW1S-083016	N	8/30/2016	T	JC26754	**373**	
GPS-MW2S	GPS-MW2S-060316	N	6/3/2016	T	JC21504	21.2	
GPS-MW2S	GPS-MW2S-083016	N	8/30/2016	T	JC26754	10.2	
GPS-MW3S	GPS-MW3S-060316	N	6/3/2016	T	JC21504	1.7	J
GPS-MW3S	GPS-MW3S-083016	N	8/30/2016	T	JC26754	4.2	J

Table 3-1
Summary of Total Chromium Analytical Results - Shallow Groundwater
Capillary Break Design - Final Report (Revision 2)
PPG, Jersey City, New Jersey

					Analyte	CHROMIUM	
					CAS RN	7440-47-3	
					GWQS	70	
					Units	ug/L	
Well ID	Sample ID	Sample Type	Sample Date	Fraction	Lab SDG	Result	Qualifier
GPS-MW4S	GPS-MW4S-060316	N	6/3/2016	T	JC21504	2.0	J
GPS-MW4S	GPS-MW4S-083016	N	8/30/2016	T	JC26754	1.3	J
GPS-MW6S	114-ABPT-MW6S-011415	N	1/14/2015	T	JB86375A	**500**	
GPS-MW6S	114-ABPT-MW6S-040715	N	4/7/2015	T	JB91794	**688**	
GPS-MW7S	114-ABPT-MW7S-010615	N	1/6/2015	T	JB85757A	13.2	
GPS-MW7S	114-ABPT-MW7S-040715	N	4/7/2015	T	JB91794	48.7	
GPS-PZ1S	114-ABPT-PZ1S-010615	N	1/6/2015	T	JB85757A	**130**	
GPS-PZ1S	114-ABPT-PZ1S-040715	N	4/7/2015	T	JB91794	**132**	
GPS-PZ2S	114-ABPT-PZ2S-010615	N	1/6/2015	T	JB85757A	2.9	J
GPS-PZ2S	114-ABPT-PZ2S-040715	N	4/7/2015	T	JB91794	3.3	J
GPS-PZ3S	114-ABPT-PZ3S-010615	N	1/6/2015	T	JB85757A	**709**	**J**
GPS-PZ3S	114-ABPT-PZ3S-040715	N	4/7/2015	T	JB91794	**396**	
GPS-PZ4S	114-ABPT-PZ4S-010615	N	1/6/2015	T	JB85757A	**1860**	**J**
GPS-PZ4S	114-ABPT-PZ4S-040715	N	4/7/2015	T	JB91794	**769**	
GPS-PZ5S	114-ABPT-PZ5S-010615	N	1/6/2015	T	JB85757A	47.1	
GPS-PZ5S	114-ABPT-PZ5S-040715	N	4/7/2015	T	JB91794	15.9	
GPS-PZ6S	114-IRMI-S-PZ6S-20150512	N	5/12/2015	T	JB94511	**2910**	**J**
HSS-P3C-MW1S	HSS-P3C-MW1S-20161219	N	12/19/2016	T	JC33993	< 0.81	UB
HSS-P3C-MW1S	HSS-P3C-MW1S-20170316	N	3/16/2017	T	JC39023	1.2	J
HSS-P3C-MW2S	HSS-P3C-MW2S-20160616	N	6/16/2016	T	JC22356	26.3	
HSS-P3C-MW2S	HSS-P3C-MW2S-20161215	N	12/15/2016	T	JC33793	6.0	JB
MW1C-3	MW1C-3-20151217	N	12/17/2015	T	JC10941	**6690**	**J**
MW1C-4	MW1C-4-20151217-12.5	N	12/17/2015	T	JC10941	**157000**	**J**
MW1C-4	MW1C-4-20141217-15.5	N	12/17/2015	T	JC10941	**637000**	**J**
MW-31A	MW31A-20151217-13.0	N	12/17/2015	T	JC10941	9.0	J
MW-31A	MW-31A-20151217-15.0	N	12/17/2015	T	JC10941	39.9	J
MW-31A	MW-31A-20170403	N	4/3/2017	T	JC40254	1.2	J
MW-34	MW34-20151214-10.5	N	12/14/2015	T	JC10597	**209**	
MW-34	MW34-20151214-15.5	N	12/14/2015	T	JC10597	**191**	
MW-35	114-MW-35-20151215-10.5	N	12/15/2015	T	JC10722	**961**	
MW-35	114-MW-35-20151215-15.5	N	12/15/2015	T	JC10722	**1460**	
MW4S	NJD981084668-10/24/2007-4	N	10/24/2007	T		6.9	B
MW4S	MW-4S-GA01-9.0	N	6/21/2011	T	460279271	18.9	
MW6S	114-MW6S-GA01-9.5	N	6/20/2011	T	460278911	< 4.1	U
MW6S	114-MW6S-GA01-12	N	6/20/2011	T	460278911	< 4.1	U
MW6S	MW-6S	N	1/5/2012	T	460354271	< 3.9	U
MW6S	MW-6S 022012	N	2/20/2012	T	JA99765	5.5	
MW8S	G000005480-3/7/2014-MW-8S	N	3/7/2014	T	JB61314	16.3	
MW8S	MW8S-9.5-20151001	N	10/1/2015	T	JC5237A	1.9	J
MW-Morris1A	MW-MORRIS-1A-20150924	N	9/24/2015	T	JC4675A	**72.6**	
MW-Morris1A	114-MW-MORRIS1A-20160321	N	3/21/2016	T	JC16664	14.6	
MW-Morris1A	MW-MORRIS1A-20170331	N	3/31/2017	T	JC40140	1.3	J
PZ1-1	114-PLT1-1-20170403	N	4/3/2017	T	JC40254R	2.2	J
PZ1-1	PZ1-1-20170524	N	5/24/2017	T	JC44024	1.4	J
PZ2-1	114-PLT2-1-20160624	N	6/24/2016	T	JC22940	< 0.81	U
PZ2-1	114-PLT2-1-20160624X	FD	6/24/2016	T	JC22940	< 0.81	U
PZ2-1	114-PLT2-1-20160916X	FD	9/16/2016	T	JC27821	5.2	J
PZ2-1	114-PLT2-1-20160916	N	9/16/2016	T	JC27821	5.1	J
PZ3-1	114-PLT3-1-20160624	N	6/24/2016	T	JC22940	1.6	J
PZ3-1	114-PLT3-1-20160916	N	9/16/2016	T	JC27821	< 0.81	U
PZ4-1	114-PLT4-1-20160624	N	6/24/2016	T	JC22940	3.6	J
PZ4-1	114-PLT4-1-20160916	N	9/16/2016	T	JC27821	1.4	J
PZ5-1	114-PLT5-1-20160624	N	6/24/2016	T	JC22940	< 0.81	U
PZ5-1	114-PLT5-1-20160916	N	9/16/2016	T	JC27821	< 0.81	U

Notes:

All data presented will undergo the appropriate level of data validation required per the project requirements prior to finalization of this draft document. Data validati
results will be presented as part of an adendum to this document.

Bolded Value - Indicates exceedance of NJDEP's Groundwater Quality Standard (GWQS).

CAS RN - Chemical Abstract Service Registry Number

Fraction: T - total/unfiltered

NJDEP - New Jersey Department of Environmental Protection

Sample type N - normal environmental sample

Sample type FD - field duplicate sample

µg/L - micrograms per liter

Qualifier Definitions:

B - Indicates the result was less than or equal to the maximum laboratory blank contamination, and was therefore negated.

J - Indicates the result was an estimated value; the associated numerical value was an approximate concentration of the analyte in the sample.

JB - Indicates the analyte concentration is greater than 3 times, but less than or equal to ten times the concentration in the associated method blank. The presence
of the analyte in the sample is considered real; the concentration is quantitatively qualified (JB) due to method blank contamination.

U - Indicates that the analyte was not detected in the sample above the sample reporting limit.

UB - The analyte concentration is less than or equal to 3 times the concentration in the associated method/prep blank. The presence of the analyte in the sample is negated (UB) due to laboratory contamination.

UJ - Indicates that the analyte was not detected above the reporting limit and the reporting limit was approximate.

Table 3-2
Summary of Total Chromium Analytical Results - Intermediate Groundwater
Capillary Break Design - Final Report (Revision 2)
PPG, Jersey City, New Jersey

					Analyte	**CHROMIUM (TOTAL)**	
					CAS RN	**7440-47-3**	
					GWQS	**70**	
					Units	**ug/L**	
Well ID	**Sample ID**	**Sample Type**	**Sample Date**	**Fraction**	**Lab SDG**	**Result**	**Qualifier**
114-MC-EW103	114-MC-EW103-20160322	N	3/22/2016	T	JC16738	**1070**	
114-MC-EW103	114-MC-EW103-20160623	N	6/23/2016	T	JC22854	**388**	
114-MC-PZ103	114-MC-PZ103-20160321	N	3/21/2016	T	JC16664	**12400**	
114-MC-PZ103	114-MC-PZ103-20160623	N	6/23/2016	T	JC22854	**15000**	
114-MC-PZ203	114-MC-PZ203-20160322	N	3/22/2016	T	JC16738	**173000**	
114-MC-PZ203	114-MC-PZ203-20160623	N	6/23/2016	T	JC22854	**215000**	
114-MW14B	PPG114-MW14BJ61161-3	N	5/14/2007	T	J61161	11	J
114-MW14B	114-MW14B-GA01-30.5	N	6/16/2011	T	460277521	< 4.1	U
114-MW19B	114-MW19B-GA01-47.5	N	6/14/2011	T	460276501	12.4	
114-MW19B	G000005480-3/5/2014-PPG-114-MW-19B	N	3/5/2014	T	JB61130	< 0.92	
114-MW20B	G000005480-2/27/2014-PPG-114-MW-20B	N	2/27/2014	T	JB60752	**203000**	
114-MW20B	114-MW20B-36.0-20151001	N	10/1/2015	T	JC5237A	**52000**	**J**
114-MW21B	PPG114-MW21BJ60618-11	N	5/10/2007	T	J60618	**1840000**	**J**
114-MW21B	114-MW21B-GA01-31.5	N	6/14/2011	T	460276501	**392000**	
114-MW22B	114-MW22B-GA01-29.5	N	6/15/2011	T	460277151	**38800**	
114-MW22B	G000005480-4/1/2014-PPG-114-MW-22B	N	4/1/2014	T	JB63510	**2510**	
114-MW23B	MW23B	N	1/6/2012	T	460354711	**25800**	
114-MW23B	MW-23B 022012	N	2/20/2012	T	JA99765	**35300**	
114-MW25B	114-MW25B	N	4/24/2014	T	JB65499A	**25100**	
114-MW25B	114-MW25B-20150720	N	7/20/2015	T	JB99503A	**2940**	
114-MW24B	114-MW24B-20150722	N	7/22/2015	T	JB99718A	3.9	J
114-MW27B	114-MW27B	N	4/24/2014	T	JB65499A	6.8	J
114-MW27B	114-MW27B-20150720	N	7/20/2015	T	JB99503A	1.2	J
114-MW36B	114-MW36B-20150721	N	7/21/2015	T	JB99605A	**105**	
114-MW37B	114-MW37B-20150722	N	7/22/2015	T	JB99718A	1.9	J
114-MW37B	114-MW37B-20150722X	FD	7/22/2015	T	JB99718A	1.4	J
114-MW38B	114-MW38B-20150723	N	7/23/2015	T	JB99807A	3.7	J
114-P1A-MW101I	114-P1A-MW101I-20160317	N	3/17/2016	T	JC16446	**10600**	
114-P1A-MW101I	114-P1A-MW101I-20160617	N	6/17/2016	T	JC22504	**8710**	
114-P1A-MW101I	114-P1A-MW101I-20160617X	FD	6/17/2016	T	JC22504	**8830**	
114-P1B-MW101I	114-P1B-MW101I-20160323	N	3/23/2016	T	JC16843	**140000**	
114-P1B-MW101I	114-P1B-MW101I-20160621	N	6/21/2016	T	JC22642	**149000**	
114-P1B-MW102I	114-P1B-MW102I-20160622	N	6/22/2016	T	JC22758	**328**	
114-P1B-MW102I	114-P1B-MW102I-20160916	N	9/16/2016	T	JC27812	**541000**	
114-P1C-EW1	114-P1C-EW1-04282015	N	4/28/2015	T	JB93509	**9590**	**J**
114-P1C-EW1	114-P1C-EW1-20150618	N	6/18/2015	T	JB97353A	**12800**	**J**
114-P1C-MW101I	114-P1C-MW101I-20160316	N	3/16/2016	T	JC16336	**4990**	
114-P1C-MW101I	114-P1C-MW101I-20160620	N	6/20/2016	T	JC22555	**6230**	
114-P1C-PZ1	114-P1C-PZ1-20160624	N	6/24/2016	T	JC22933	**3720**	
114-P1C-PZ1	114-P1C-PZ1-20160912	N	9/12/2016	T	JC27433	**1620**	
114-P1C-PZ2	114-P1C-PZ2-20160624	N	6/24/2016	T	JC22933	**629**	
114-P1C-PZ2	114-P1C-PZ2-20160912	N	9/12/2016	T	JC27433	**615**	
114-P2A-MW101I	114-P2A-MW101I-20160914	N	9/14/2016	T	JC27595	12.4	
114-P2A-MW101I	114-P2A-MW101I-20161212	N	12/12/2016	T	JC33522	4.6	J
114-P2A-MW102I	114-P2A-MW102I-20160914	N	9/14/2016	T	JC27595	8.8	J
114-P2A-MW102I	114-P2A-MW102I-20161219	N	12/19/2016	T	JC33991	7.7	JB
114-P2A-MW103I	114-P2A-MW103I-20160915	N	9/15/2016	T	JC27716	7.2	J
114-P2A-MW103I	114-P2A-MW103I-20161214	N	12/14/2016	T	JC33691	23.2	
114-P2A-MW104I	114-P2A-MW104I-20160915	N	9/15/2016	T	JC27716	4.0	J
114-P2A-MW104I	114-P2A-MW104I-20161219	N	12/19/2016	T	JC33991	< 0.81	UB
114-P2B1-MW101I	114-P2B1-MW101I-20160322	N	3/22/2016	T	JC16738	**1520000**	
114-P2B1-MW101I	114-P2B1-MW101I-20160620	N	6/20/2016	T	JC22555	**1320000**	
114-P2B2-MW101I	114-P2B2-MW101I-20160323	N	3/23/2016	T	JC16843	**413000**	
114-P2B2-MW101I	114-P2B2-MW101I-20160323X	FD	3/23/2016	T	JC16843	**410000**	
114-P2B2-MW101I	114-P2B2-MW101I-20160620	N	6/20/2016	T	JC22555	**473000**	
114-P2B3-MW101I	114-P2B3-MW101I-20160323	N	3/23/2016	T	JC16843	**365000**	
114-P2B3-MW101I	114-P2B3-MW101I-20160622	N	6/22/2016	T	JC22758	**142000**	**J**
114-P2B4-MW101I	114-P2B4-MW101I-20160323	N	3/23/2016	T	JC16843	**500000**	**J**
114-P2B4-MW101I	114-P2B4-MW101I-20160621	N	6/21/2016	T	JC22642	**224000**	
114-P2B4-MW101I	114-P2B4-MW101I-20160621X	FD	6/21/2016	T	JC22642	**221000**	**J**
114-P2B4-MW102I	114-P2B4-MW102I-20160322	N	3/22/2016	T	JC16738	**89700**	**J**
114-P2B4-MW102I	114-P2B4-MW102I-20160621	N	6/21/2016	T	JC22642	**16200**	**J**
114-P2B4-MW103I	114-P2B4-MW103I-20160316	N	3/16/2016	T	JC16336	19.5	J
114-P2B4-MW103I	114-P2B4-MW103I-20160622X	FD	6/22/2016	T	JC22758	6.3	JB
114-P2B4-MW103I	114-P2B4-MW103I-20160622	N	6/22/2016	T	JC22758	9.2	JB

Table 3-2
Summary of Total Chromium Analytical Results - Intermediate Groundwater
Capillary Break Design - Final Report (Revision 2)
PPG, Jersey City, New Jersey

					Analyte	CHROMIUM (TOTAL)	
					CAS RN	7440-47-3	
					GWQS	70	
					Units	ug/L	
Well ID	**Sample ID**	**Sample Type**	**Sample Date**	**Fraction**	**Lab SDG**	**Result**	**Qualifier**
132-MW2B	PPG132-MW2BJ61161-11	N	5/15/2007	T	J61161	**84.6**	**BF**
132-MW2B	132-MW2B-GA01-27.5	N	6/17/2011	T	460278051	9.4	
132-P3A-MW102I	132-P3A-MW102I-20160317	N	3/17/2016	T	JC16446	68.1	
132-P3A-MW102I	132-P3A-MW102I-20160617	N	6/17/2016	T	JC22504	10.2	J
132-P3A-MW103I	132-P3A-MW103I-20160318	N	3/18/2016	T	JC16549	**30400**	
132-P3A-MW103I	132-P3A-MW103I-20160616	N	6/16/2016	T	JC22356	**20900**	**J**
132-P3A-MW104I	132-P3A-MW104I-20160318	N	3/18/2016	T	JC16549	2.9	J
132-P3A-MW104I	132-P3A-MW104I-20160616	N	6/16/2016	T	JC22356	1.5	J
133-MW1B	133-MW1B	N	1/20/2012	T	460359981	< 3.9	U
133-MW1B	133-MW1BX	FD	1/20/2012	T	460359981	< 3.9	U
133-MW1B	G000005480-4/4/2014-PPG-133-MW-1B	N	4/4/2014	T	JB63798	< 0.89	
133-MW2B	PPG133-MW2BJ61161-16	N	5/16/2007	T	J61161	< 10	UJ
133-MW2B	133-MW2B-GA01-32.5	N	6/20/2011	T	460278911	< 4.1	U
133-P3C-MW101I	133-P3C-MW101I-20160913	N	9/13/2016	T	JC27486	2.9	J
133-P3C-MW101I	133-P3C-MW101I-20161215	N	12/15/2016	T	JC33793	4.0	JB
133-P3C-MW102I	133-P3C-MW102I-20160913	N	9/13/2016	T	JC27486	1.8	J
133-P3C-MW102I	133-P3C-MW102I-20161216	N	12/16/2016	T	JC33887	6.0	JB
135-MW1B	135-MW1B-GA01-30.0	N	6/27/2011	T	460281431	17.7	J
135-MW1B	G000005480-2/28/2014-PPG-135-MW1B	N	2/28/2014	T	JB60865	< 0.92	U
135-MW2B	G000005480-2/28/2014-PPG-135-MW2B	N	2/28/2014	T	JB60865	< 0.92	U
135-MW2B	G000005480-2/28/2014-PPG-135-MW2B-DUP	FD	2/28/2014	T	JB60865	< 0.92	U
135-MW2B	135-MW2B-30.5	N	10/6/2015	T	JC5499	5.7	J
135-MW3B	G000005480-2/28/2014-PPG-135-MW3B	N	2/28/2014	T	JB60865	< 0.92	U
137-MW1B	137-MW1B-GA01-30.5	N	6/23/2011	T	460280421	15.6	
137-MW1B	G000005480-4/1/2014-PPG-137-MW-1B	N	4/1/2014	T	JB63510	41.2	
137-MW1B	G000005480-4/1/2014-PPG-137-MW-1B-DUP	FD	4/1/2014	T	JB63510	31.8	
137-MW2B	PPG137-MW2BJ61161-14	N	5/15/2007	T	J61161	**1210**	**J**
137-MW2B	137-MW2B-GA01-30.5	N	6/29/2011	T	460282441	**641**	
137-MW4B	137-MW4B-0412	N	4/2/2012	T	JB3153	40.0	
137-MW4B	G000005480-3/6/2014-PPG-137-MW-4B	N	3/6/2014	T	JB61212	20.6	
137-P3B-MW101I	137-P3B-MW101I-20160323	N	3/23/2016	T	JC16843	**7960**	
137-P3B-MW101I	137-P3B-MW101I-20160624	N	6/24/2016	T	JC22939	**140**	
137-P3B-MW102I	137-P3B-MW102I-20160321	N	3/21/2016	T	JC16664	18.4	
137-P3B-MW102I	137-P3B-MW102I-20160615	N	6/15/2016	T	JC22273	1.5	J
143-P3A-MW101I	143-P3A-MW101I-20160318	N	3/18/2016	T	JC16549	**14100**	
143-P3A-MW101I	143-P3A-MW101I-20160620	N	6/20/2016	T	JC22555	**10700**	
GPS-EW1I	GPS-EW1I-071216	N	7/12/2016	T	JC23920	**74.6**	
GPS-EW1I	GPS-EW1I-100616	N	10/6/2016	T	JC29150	**121**	
GPS-EW2I	GPS-EW2I-071216	N	7/12/2016	T	JC23920	**342**	
GPS-EW2I	GPS-EW2I-100616	N	10/6/2016	T	JC29150	**287**	
GPS-IW10I	114-GWPS-IW-10I	N	1/2/2014	T	JB56954	**114000**	
GPS-IW12I	GPS-IW12I-071216	N	7/12/2016	T	JC23920	**166**	
GPS-IW12I	GPS-IW12I-100616	N	10/6/2016	T	JC29150	**215**	
GPS-IW1I	114-ABPT-IW1I-010515	N	1/5/2015	T	JB85412A	**6750**	
GPS-IW1I	114-ABPT-IW1I-040815	N	4/8/2015	T	JB91941	**4040**	
GPS-IW2I	114-ABPT-IW2I-010615	N	1/6/2015	T	JB85757A	**2030**	**J**
GPS-IW2I	114-ABPT-IW2I-040815	N	4/8/2015	T	JB91941	**451**	
GPS-IW3I	GPS-IW3I-071216	N	7/12/2016	T	JC23920	**70.8**	
GPS-IW3I	GPS-IW3I-100616	N	10/6/2016	T	JC29150	**108**	
GPS-IW6I	GPS-IW6I-071216	N	7/12/2016	T	JC23920	**80.4**	
GPS-IW6I	GPS-IW6I-100616	N	10/6/2016	T	JC29150	**85.2**	
GPS-IW9I	GPS-IW9I-071216	N	7/12/2016	T	JC23920	**106**	
GPS-IW9I	GPS-IW9I-100616	N	10/6/2016	T	JC29150	56.2	
GPS-MW1I	114-GWPS-MW1I-BL	N	5/29/2013	T	JB38265	**86200**	
GPS-MW1I	114-GWPS-MW1I-BLX	FD	5/29/2013	T	JB38265	**85100**	
GPS-MW2I	114-ABPT-MW2I-010515	N	1/5/2015	T	JB85412A	**195000**	**J**
GPS-MW2I	114-ABPT-MW2I-040815	N	4/8/2015	T	JB91941	**150000**	**J**
GPS-MW3I	114-ABPT-MW3I-010515	N	1/5/2015	T	JB85412A	**20100**	**J**
GPS-MW3I	114-ABPT-MW3I-040815	N	4/8/2015	T	JB91941	**21400**	**J**
GPS-MW4I	114-ABPT-MW4I-010515	N	1/5/2015	T	JB85412A	**128**	**J**
GPS-MW4I	114-ABPT-MW41-040715	N	4/7/2015	T	JB91794	**147**	
GPS-MW5I	GPS-MW5I-071216	N	7/12/2016	T	JC23920	**236**	
GPS-MW5I	GPS-MW5I-100616	N	10/6/2016	T	JC29150	**92.4**	
GPS-MW6I	GPS-MW6I-071216	N	7/12/2016	T	JC23920	**34800**	
GPS-MW6I	GPS-MW6I-100616	N	10/6/2016	T	JC29150	**91300**	

Table 3-2
Summary of Total Chromium Analytical Results - Intermediate Groundwater
Capillary Break Design - Final Report (Revision 2)
PPG, Jersey City, New Jersey

					Analyte	**CHROMIUM (TOTAL)**	
					CAS RN	**7440-47-3**	
					GWQS	**70**	
					Units	**ug/L**	
Well ID	**Sample ID**	**Sample Type**	**Sample Date**	**Fraction**	**Lab SDG**	**Result**	**Qualifier**
GPS-MW7I	GPS-MW7I-071216	N	7/12/2016	T	JC23920	**125**	
GPS-MW7I	GPS-MW7I-100616	N	10/6/2016	T	JC29150	**74.5**	
GPS-PZ1I	114-ABPT-PZ1I-010515	N	1/5/2015	T	JB85412A	**153000**	**J**
GPS-PZ1I	114-ABPT-PZ1I-040815	N	4/8/2015	T	JB91941	**127000**	**J**
GPS-PZ2I	114-ABPT-PZ21-010515	N	1/5/2015	T	JB85412A	**916**	
GPS-PZ2I	114-ABPT-PZ2I-040815	N	4/8/2015	T	JB91941	**1360**	**J**
GPS-PZ3I	114-ABPT-PZ3I-010515	N	1/5/2015	T	JB85412A	**2470**	
GPS-PZ3I	114-ABPT-PZ3I-040815	N	4/8/2015	T	JB91941	**2230**	
GPS-PZ4I	114-ABPT-PZ4I-010515	N	1/5/2015	T	JB85412A	**18500**	
GPS-PZ4I	114-ABPT-PZ4I-040815	N	4/8/2015	T	JB91941	**1390**	**J**
GPS-PZ5I	114-ABPT-PZ5I-010515	N	1/5/2015	T	JB85412A	**109000**	**J**
GPS-PZ5I	114-ABPT-PZ5I-040815	N	4/8/2015	T	JB91941	**93900**	
MW11B	114-G11B-001	N	12/14/2005	T	J18099	**2050000**	**J**
MW11B	MW11B-GA01-31.0	N	6/27/2011	T	460281431	**1380000**	
MW12B	114-G12B-001	N	12/14/2005	T	J18099	**252000**	**J**
MW12B	114-G12B-101	FD	12/14/2005	T	J18099	**118000**	**J**
MW12B	MW12B-GA01-31.0	N	6/23/2011	T	460280421	**219000**	
MW1B	114-G1B004	N	9/12/2005	T	J9469	**51700**	
MW1B	MW1B-GA01-21.5	N	6/28/2011	T	460281981	**436000**	
MW1B	MW1B-GA01-26.5	N	6/28/2011	T	460281981	**436000**	
MW1D	NJD981084668-10/23/2007-1	FD	10/23/2007	T		**434000**	
MW1D	NJD981084668-10/23/2007-3	N	10/23/2007	T		**434000**	
MW1D	MW1D-GA01-36.5	N	6/24/2011	T	460280981	**582000**	
MW1D	MW1D-GA01-42.5	N	6/24/2011	T	460280981	**576000**	
MW2B	G2B002	N	1/19/2004	T	R2419863	**140**	**BF**
MW2B	114-G2B003	N	9/9/2005	T	J9282	**79.9**	
MW2D	NJD981084668-10/23/2007-5	N	10/23/2007	T		**516000**	
MW2D	MW2D-GA01-35.5	N	6/30/2011	T	460282971	**446000**	
MW2D	MW2D-GA01-40.5	N	6/30/2011	T	460282971	**462000**	
MW3B	114-G3B004	N	9/8/2005	T	J9118	68.2	
MW3B	MW3B-GA01-34.5	N	6/27/2011	T	460281431	64.6	
MW3B	MW3B-GA01-39.5	N	6/27/2011	T	460281431	61.2	
MW3D	MW3D-GA01-51.0	N	6/27/2011	T	460281431	47.0	
MW3D	MW3D	N	1/6/2012	T	460354711	43.2	
MW3D	MW-3D 022012	N	2/20/2012	T	JA99765	19.9	
MW3D	MW-3DX 022012	FD	2/20/2012	T	JA99765	15.9	
MW4B	NJD981084668-10/1/2007-5	N	10/1/2007	T		**1140000**	
MW4B	NJD981084668-10/29/2007-2	N	10/29/2007	T		**1020000**	
MW4B	114-MW4B-GA01-30.5	N	6/15/2011	T	460277151	**744000**	
MW4B	114-MW4B-GA01-35.5	N	6/15/2011	T	460277151	**723000**	
MW4D	NJD981084668-10/1/2007-2	N	10/1/2007	T		3.4	B
MW4D	NJD981084668-10/24/2007-2	N	10/24/2007	T		< 1.6	U
MW4D	MW-4D-GA01-43.0	N	6/21/2011	T	460279271	< 4.1	U
MW5B	114-G5B005	N	9/9/2005	T	J9282	**494000**	
MW5B	MW5B-GA01-36.0	N	6/28/2011	T	460281981	**459000**	
MW6B	G6B002	N	1/14/2004	T	R2419863	**5430000**	
MW6B	114-G6B003	N	9/9/2005	T	J9282	**3810000**	
MW6D	MW-6D-GA01-42.5	N	6/21/2011	T	460279271	5.0	
MW6D	MW-6D-GA01-42.5X	FD	6/21/2011	T	460279271	4.4	J
MW6D	MW-6D-GA01-46.0	N	6/21/2011	T	460279271	< 4.1	U
MW6D	MW-6D	N	1/5/2012	T	460354271	13.3	
MW6D	MW-6D 022012	N	2/20/2012	T	JA99765	31.9	
MW7B	114-G7B-003	N	9/9/2005	T	J9282	**152000**	
MW7B	MW7B-GA01-28.0	N	6/29/2011	T	460282441	**96500**	
MW8B	NJD981084668-12/1/2009-114MW8B	N	12/1/2009	T	9120124	**940000**	
MW8B	MW8B-GA01-41.5	N	6/27/2011	T	460281431	**1070000**	
MW8B	MW8B-GA01-46.5	N	6/27/2011	T	460281431	**1070000**	
MW8D	G000005480-3/7/2014-MW-8D	N	3/7/2014	T	JB61314	**150000**	
MW8D	G000005480-3/7/2014-MW-8D-DUP	FD	3/7/2014	T	JB61314	**146000**	
MW8D	MW8D-41.5-20150929	N	9/29/2015	T	JC4976A	**65600**	**J**
MW8D	MW8D-46.5-20150929	N	9/29/2015	T	JC4976A	**3120**	**J**
MW9B	114-G9B-001	N	11/28/2005	T	J16625	**271000**	
MW9B	MW9B-GA01-31.5	N	6/30/2011	T	460282971	**112000**	
MW9D	MW9D-GA01-37.5	N	6/28/2011	T	460281981	16.2	
MW9D	MW9D-GA01-42.5	N	6/28/2011	T	460281981	8.7	
MW9D	G000005480-4/3/2014-MW-9D	N	4/3/2014	T	JB63769	< 0.92	

Table 3-2
Summary of Total Chromium Analytical Results - Intermediate Groundwater
Capillary Break Design - Final Report (Revision 2)
PPG, Jersey City, New Jersey

					Analyte	**CHROMIUM (TOTAL)**	
					CAS RN	**7440-47-3**	
					GWQS	**70**	
					Units	**ug/L**	
Well ID	**Sample ID**	**Sample Type**	**Sample Date**	**Fraction**	**Lab SDG**	**Result**	**Qualifier**
MW13B	114-G13B-001	N	12/15/2005	T	J18176	17.1	
MW13B	MW13B-GA01-38.0	N	6/30/2011	T	460282971	**70.8**	

Notes:

All data presented will undergo the appropriate level of data validation required per the project requirements prior to finalization of this draft document. Da validation results will be presented as part of addendum to this document.

Bolded Value - Indicates exceedance of NJDEP's Groundwater Quality Standard (GWQS).

CAS RN - Chemical Abstract Service Registry Number

Fraction: T - total/unfiltered

NJDEP - New Jersey Department of Environmental Protection

Sample type N - normal environmental sample

Sample type FD - field duplicate sample

µg/L - micrograms per liter

Qualifier Definitions:

B - Indicates the result was less than or equal to the maximum laboratory blank contamination, and was therefore negated.

BF - Indicates the result was less than or equal to the maximum field blank contamination, and was therefore negated.

J - Indicates the result was an estimated value; the associated numerical value was an approximate concentration of the analyte in the sample.

JB - The analyte concentration is greater than 3 times, but less than or equal to ten times the concentration in the associated method blank. The presence of the analyte in the sample is considered real; the concentration is quantitatively qualified (JB) due to method blank contamination.

U - Indicates that the analyte was not detected in the sample above the sample reporting limit.

UB - The analyte concentration is less than or equal to 3 times the concentration in the associated method/prep blank. The presence of the analyte in the sample is negated (UB) due to laboratory contamination.

UJ - Indicates that the analyte was not detected above the reporting limit and the reporting limit was approximate.

Table 3-3
Actual Thickness of A-DGA Material
Capillary Break Design - Final Report (Revision 2)
PPG, Jersey City, New Jersey

Phase	**Actual A-DGA Thickness (ft)**
IRM #1	10.3
Phase 1A	19.0
Phase 1B	12.7
Phase 1C	14.5
Phase 2B-1	12.3
Phase 2B-2	10.9
Phase 2B-3	13.2
Phase 2B-4	13.4
Phase 3A	5.5
Phase 3B	17.0
Phase 3C	12.7

Notes:

A-DGA - dense-grade aggregate amended with FerroBlack®-H

ft - feet

Table 5-1
Particle Size Distribution for DGA/A-DGA Material Results
Capillary Break Design - Final Report (Revision 2)
PPG, Jersey City, New Jersey

Minimum Particle Diameter	Maximum Particle Diameter	Equivalent Sieve No. (Passing)	Weight Passing (%)
2 mm	1.5 in	N/A	66
0.074 mm	< 2 mm	10	33*

Notes:
* **-** No more than 8% of this material contained fines (i.e., material passing a No. 200 sieve)

Results shown are from the Capillary Rise Study

Table 5-2
Minimum A-DGA Thickness Required for 30-Year and 100-Year Capacity and FB-H Dosage
Capillary Break Design - Final Report (Revision 2)
PPG, Jersey City, New Jersey

Phase	**Minimum A-DGA Thickness for 30-Year Capacity (ft)**	**Minimum A-DGA Thickness for 100-Year Capacity (ft)**	**FB-H Amendment Dosage (% by Weight)**
IRM #1	0.2*	0.5*	0.7%
Phase 1A	0.13*	0.4*	2.8%
Phase 1B	0.3*	1.1	0.7%
Phase 1C	0.04*	0.1*	2.8%
Phase 2B-1	2	6.7	2.0%
Phase 2B-2	1.6	5.2	0.7%
Phase 2B-3	1	3.4	0.7%
Phase 2B-4	0.7*	2.4	0.7%
Phase 3A	0.2*	0.5*	0.7%
Phase 3B	0.2*	0.5*	0.7%
Phase 3C	0.6*	1.9	0.7%

Notes:

* NJDEP requires a minimum thickness of 1 ft to ensure the appropriate coverage.

% - percent

A-DGA - dense-grade aggregate amended with FB-H

FB-H - FerroBlack®-H

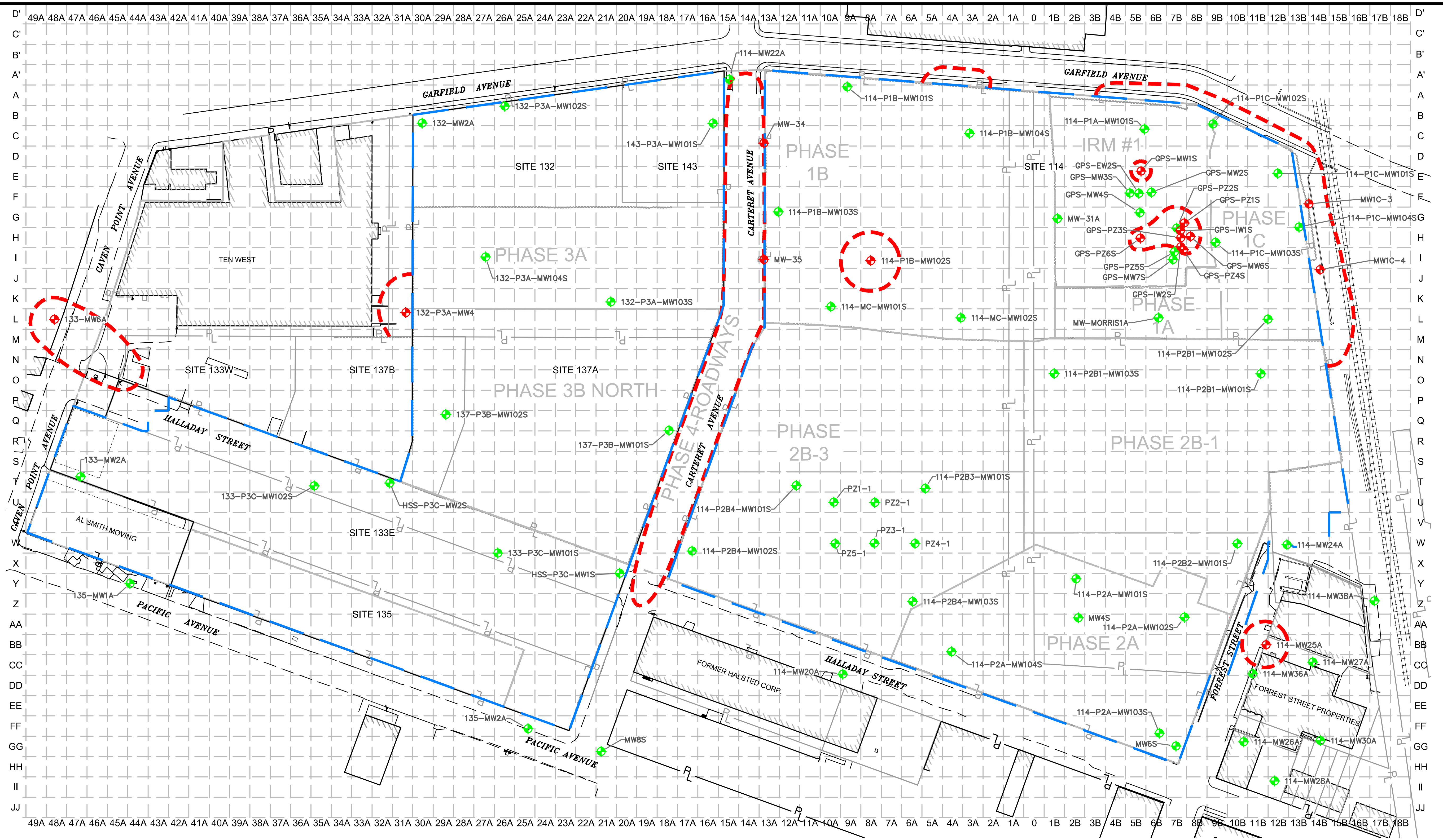
ft - foot or feet

IRM - Interim Remedial Measure

NJDEP - New Jersey Department of Environmental Protection

Figures

File: \\USCHL1FP001\Data\Projects\Jobs\Rem_Eng\Project Files\PPG Industries\Garfield Avenue\30% Design\CADD\DWGS\Cap Break\Design Report\2017-12-11 Cap Break Design Report.dwg Layout: Figure 3-1 User: si



LEGEND

🟩	MONITORING WELL - LAST 2 GW SAMPLES Cr ≤ GWQS
🟥	MONITORING WELL - LAST GW SAMPLE Cr ≥ GWQS
——℞——	PROPERTY LINE
— — —	PHASE BOUNDARY
▨	SHEET PILE
┼┼┼┼	NEW JERSEY TRANSIT LIGHT RAIL
▨	EXISTING BUILDING
——	CURB
======	EXISTING BUILDING FOUNDATION
— —	SOIL REMEDIATION COMPLETE OR TO BE COMPLETE BY END OF 2017
- - -	APPROXIMATE SHALLOW GROUNDWATER TOTAL CHROMIUM ISOPLETH - 70 μg/L

NOTES:

IN REMEDIATED AREAS, ONLY WELLS SAMPLED "POST REMEDIATION" ARE SHOWN ON THIS FIGURE.

Cr - CHROMIUM (TOTAL) GW CONCENTRATION(S)

GW - GROUNDWATER

GWQS - NJDEP GROUNDWATER QUALITY STANDARD OF 70 μg/L

NJDEP - NEW JERSEY DEPARTMENT OF ENVIRONMENTAL PROTECTION

μg/L - MICROGRAMS PER LITER

NORTH
NEW JERSEY STATE PLANE COORDINATE SYSTEM NAD 83

75 0 150
GRAPHIC SCALE IN FEET

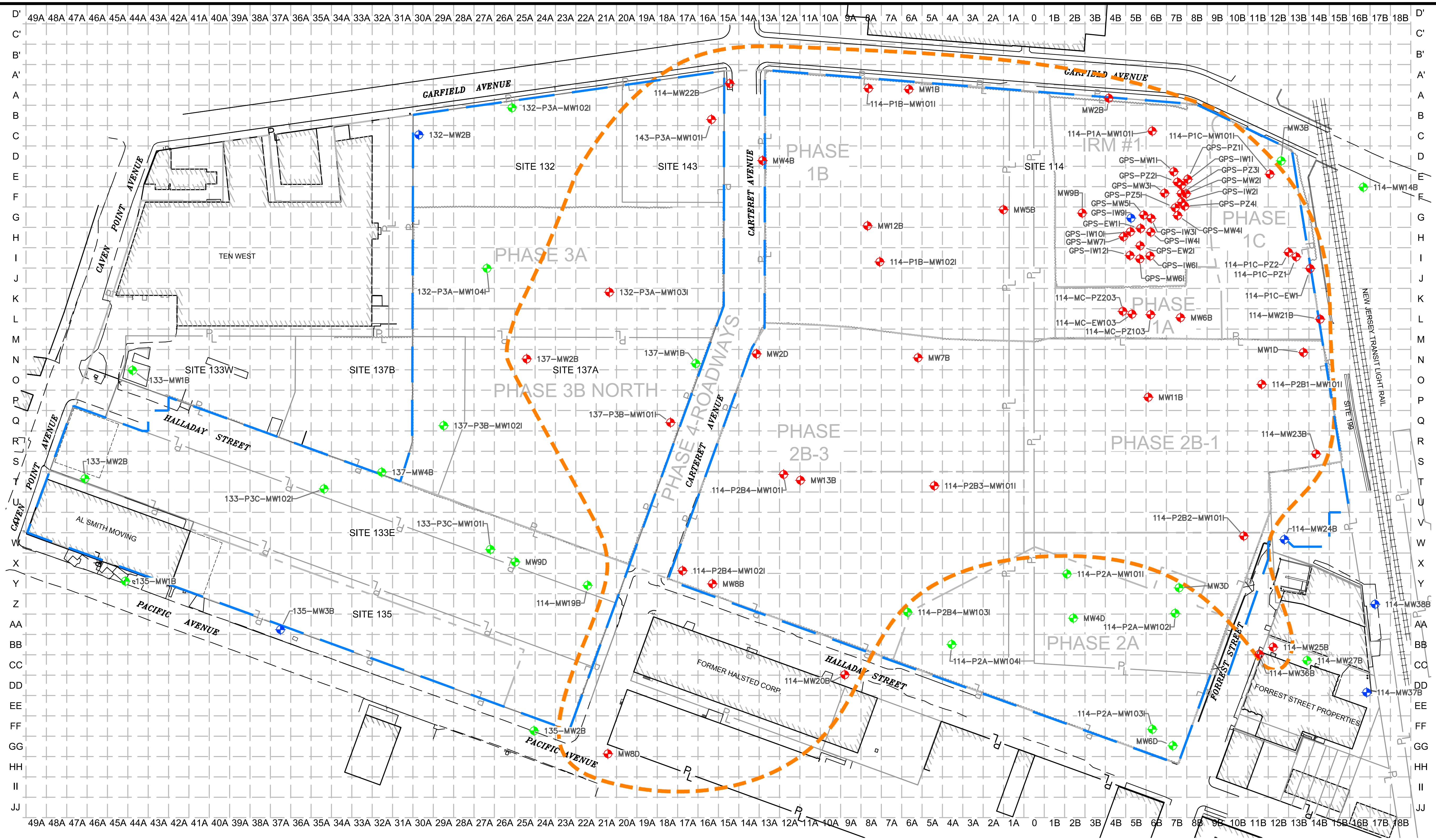
AECOM

PPG
GARFIELD AVENUE GROUP OF SITES
JERSEY CITY, NEW JERSEY

DATE: 12/11/2017
DRWN: DCB

TOTAL CHROMIUM ISOPLETHS - SHALLOW GROUNDWATER

FIGURE 3-1



LEGEND

🟢	MONITORING WELL - LAST 2 GW SAMPLES Cr ≤ GWQS
🔴	MONITORING WELL - LAST GW SAMPLE Cr ≥ GWQS
🔵	MONITORING WELL - LAST GW SAMPLE Cr ≤ GWQS
—℞—	PROPERTY LINE
— — —	PHASE BOUNDARY
~~	SHEET PILE
┼┼┼┼	NEW JERSEY TRANSIT LIGHT RAIL
▨	EXISTING BUILDING
═	CURB
= = =	EXISTING BUILDING FOUNDATION
— —	SOIL REMEDIATION COMPLETE OR TO BE COMPLETE BY END OF 2017
- - -	APPROXIMATE INTERMEDIATE GROUNDWATER TOTAL CHROMIUM ISOPLETH - 70 µg/L

NOTES:

IN REMEDIATED AREAS, ONLY WELLS SAMPLED "POST REMEDIATION" ARE SHOWN ON THIS FIGURE.

132-MW2B MONITORING WELL COULD NOT BE LOCATED FOLLOWING BUILDING DEMOLITION OR DURING EXCAVATION; NO ADDITIONAL DATA FROM THIS LOCATION IS REQUIRED PER NJDEP/WESTON DIRECTION.

Cr - CHROMIUM (TOTAL) GW CONCENTRATION(S)

GW - GROUNDWATER

GWQS - NJDEP GROUNDWATER QUALITY STANDARD OF 70 µg/L

NJDEP - NEW JERSEY DEPARTMENT OF ENVIRONMENTAL PROTECTION

µg/L - MICROGRAMS PER LITER

AECOM

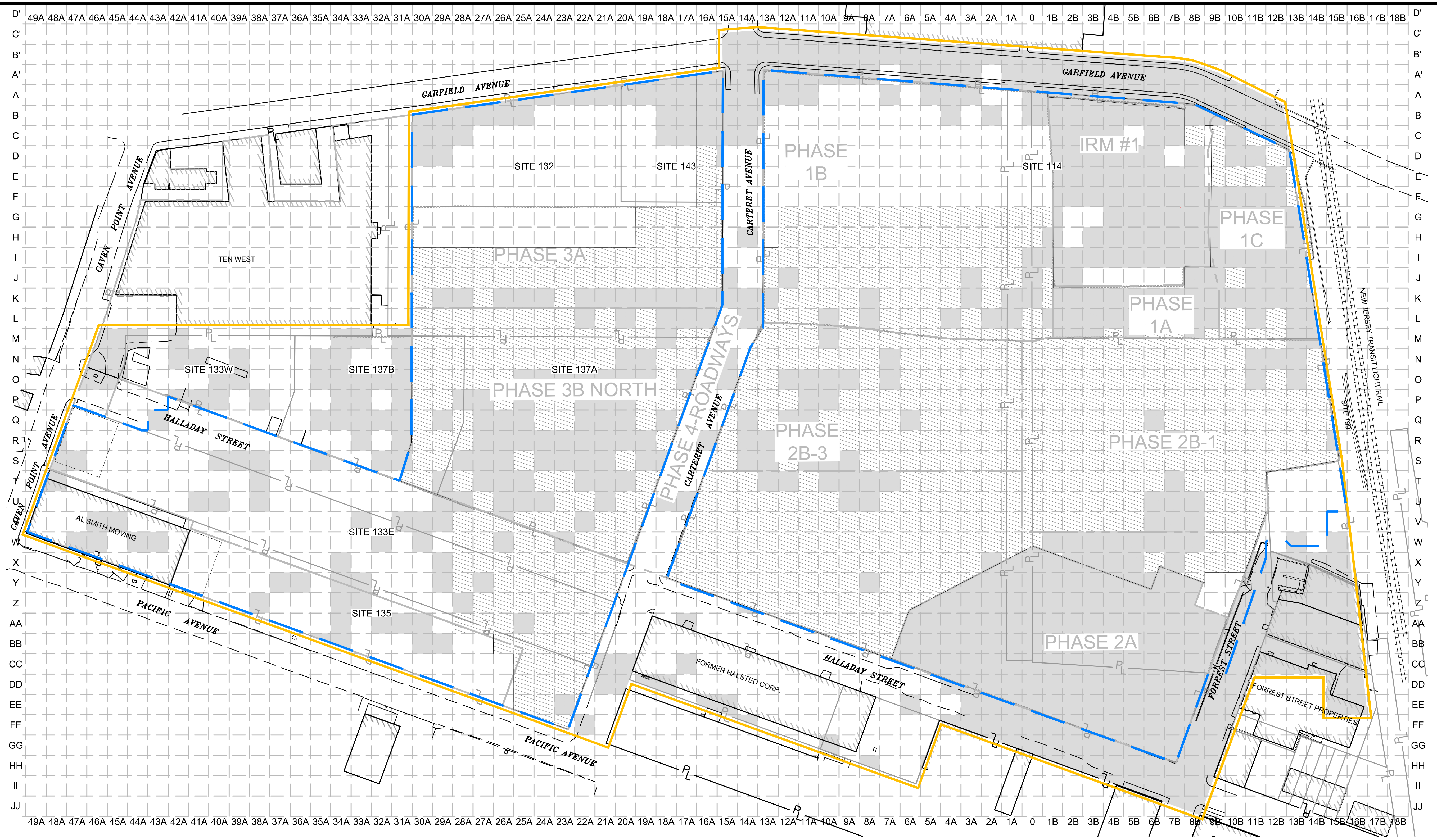
PPG
GARFIELD AVENUE GROUP OF SITES
JERSEY CITY, NEW JERSEY

TOTAL CHROMIUM ISOPLETHS - INTERMEDIATE GROUNDWATER

DATE: 06/20/2017
DRWN: DCB

FIGURE 3-2

File: \\uschl1fp001\data\Projects\Jobs\Rem_Eng\Project Files\PPG Industries\Garfield Avenue\30% Design\CADD\DWGS\Cop Break\Design Report\2017-06-20 Cop Break Design Report.dwg Layout: Figure 3-2 User: lam.



LEGEND

PROPERTY LINE
PHASE BOUNDARY
SHEET PILE
NEW JERSEY TRANSIT LIGHT RAIL
EXISTING BUILDING
CURB
EXISTING BUILDING FOUNDATION

SOIL REMEDIATION COMPLETE OR TO BE COMPLETE BY END OF 2017

LIMIT OF AREA INCLUDED IN EXTENT OF MM ANALYSIS

COMPETENT MM ABSENT - BASED ON EXISTING DATA OR A LACK OF DATA

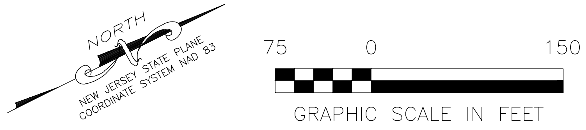
EXTENT OF FERROBLACK-H AMENDED BACKFILL PLACED FROM BASE OF EXCAVATION TO ELEVATION 11.0 (FT NAVD88)

NOTES:

COMPETENT MM - INDICATES MM PRESENT AT A MINIMUM THICKNESS OF 1 FOOT

FT NAVD88 - FEET NORTH AMERICAN VERTICAL DATUM OF 1988

MM - MEADOW MAT



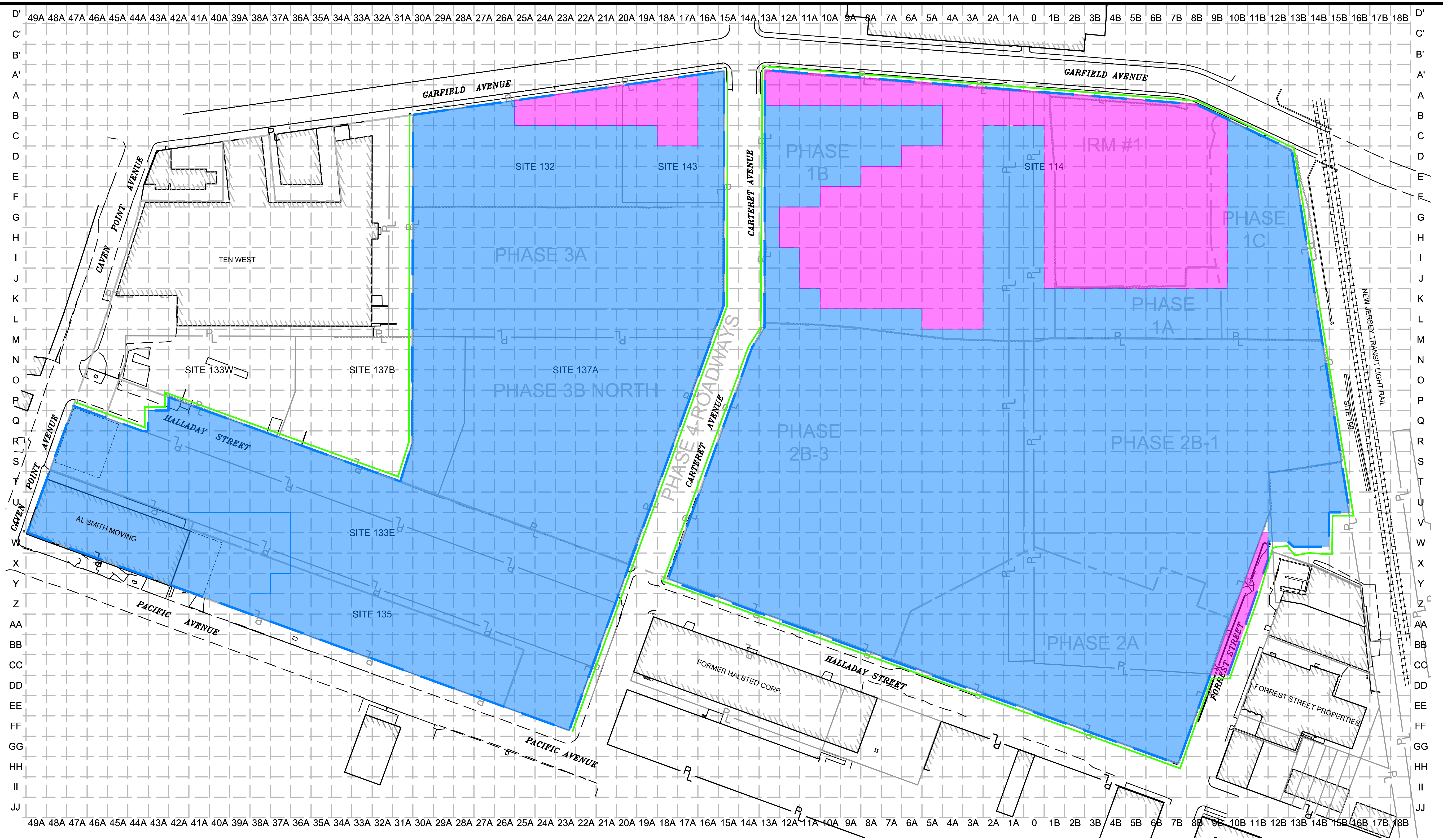
AECOM

PPG
GARFIELD AVENUE GROUP OF SITES
JERSEY CITY, NEW JERSEY

DATE: 06/22/2017 DRWN: TDL

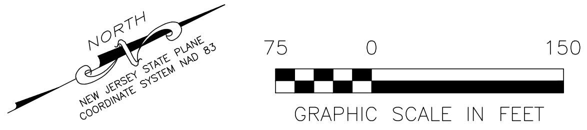
EXTENT OF COMPETENT MEADOW MAT AND FERROBLACK-H AMENDED BACKFILL REMEDIATED AREAS AND ROADWAYS

FIGURE 3-3



LEGEND

—PL—	PROPERTY LINE
— — —	PHASE BOUNDARY
~~	SHEET PILE
┿┿┿┿	NEW JERSEY TRANSIT LIGHT RAIL
▨	EXISTING BUILDING
═	CURB
- - - -	EXISTING BUILDING FOUNDATION
🟪	AREAS REQUIRING CAPILLARY BREAK
🟦	AREAS WHERE CAPILLARY BREAK IS NOT REQUIRED
━ ━	SOIL REMEDIATION COMPLETE OR TO BE COMPLETE BY THE END OF 2017
🟩	BOUNDARY OF UNREMEDIATED AREA ADJACENT TO REMEDIATED AREA



AECOM

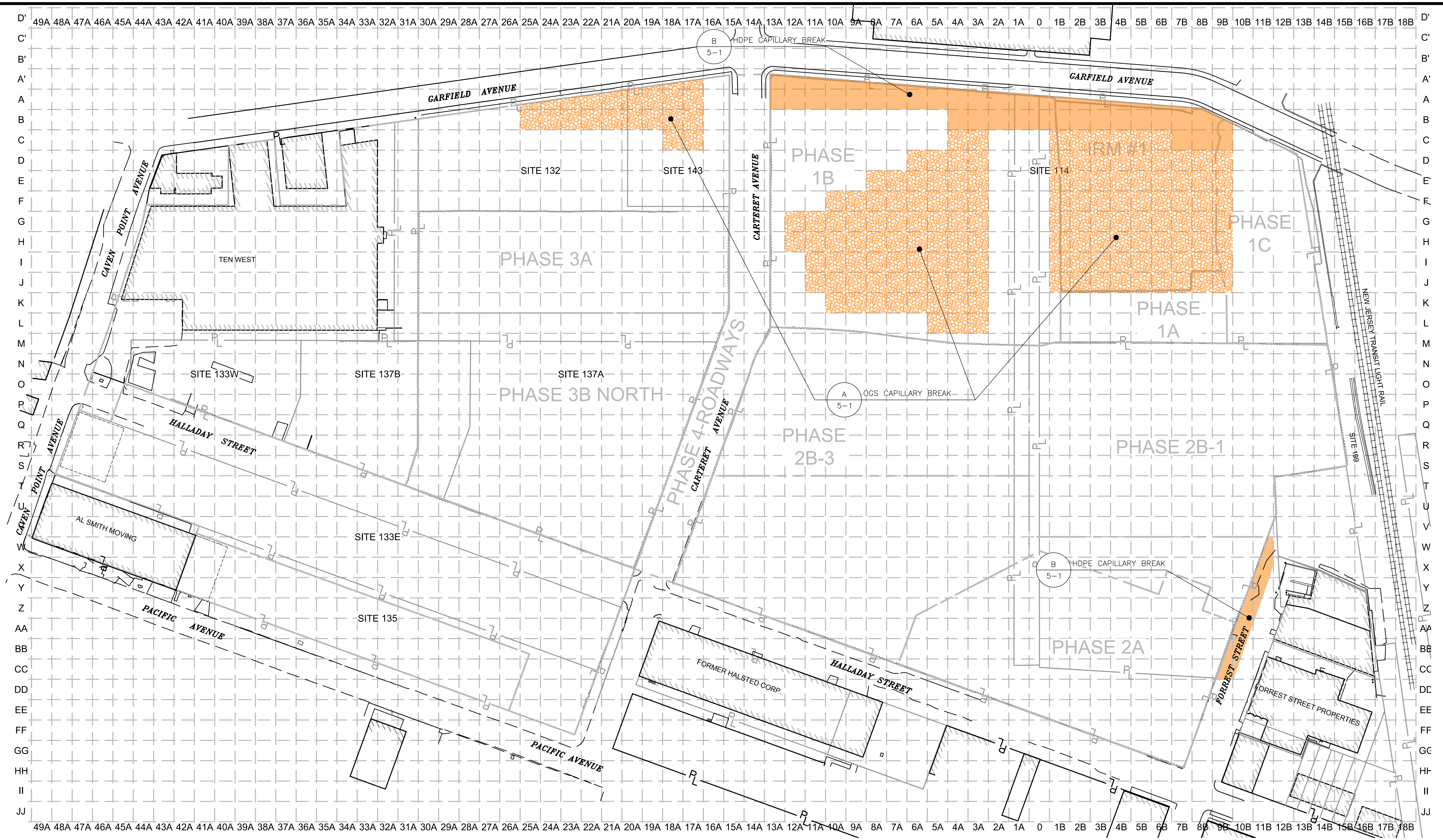
PPG
GARFIELD AVENUE GROUP OF SITES
JERSEY CITY, NEW JERSEY

DATE: 06/20/2017 DRWN: TDL

PROPOSED CAPILLARY BREAK EXTENT

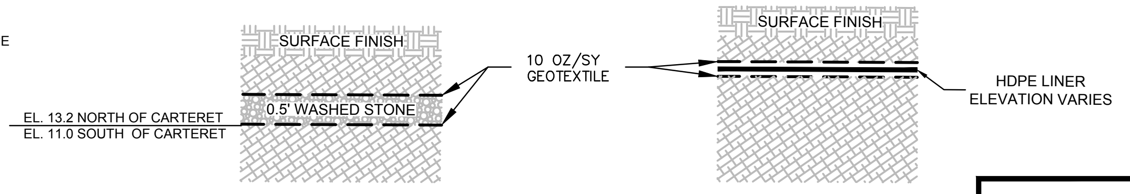
FIGURE 4-1

File: \\uschl1fp001\data\Projects\Jobs\Rem_Eng\Project Files\PPG Industries\Garfield Avenue\30% Design\CADD\DWGS\Cap Break\Design Report\2017-06-20 Cap Break Design Report.dwg Layout: Figure 4-1 User: lam.



LEGEND

—℄—	PROPERTY LINE
— — —	PHASE BOUNDARY
~~	SHEET PILE
┼┼┼┼┼	NEW JERSEY TRANSIT LIGHT RAIL
▨	EXISTING BUILDING
═	CURB
- - - -	EXISTING BUILDING FOUNDATION
▨	PROPOSED EXTENT OF OGS CAPILLARY BREAK
■	PROPOSED EXTENT OF HDPE CAPILLARY BREAK



A 5-1 OGS CAPILLARY BREAK

B 5-1 HDPE CAPILLARY BREAK

NOTES:

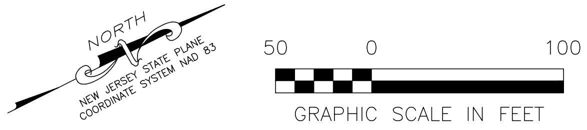
EL - ELEVATION (FT NAVD88)

FT NAVD88 - FEET NORTH AMERICAN VERICAL DATUM OF 1988

HDPE - HIGH-DENSITY POLYETHYLENE

OZ/SY - OUNCES PER SQUARE YARD

OGS - OPEN GRADE STONE



AECOM

PPG
GARFIELD AVENUE GROUP OF SITES
JERSEY CITY, NEW JERSEY

DATE: 06/20/2017
DRWN: TDL

CAPILLARY BREAK MATERIALS PLAN

FIGURE 5-1

File: \\uschl1fp001\data\Projects\Jobs\Rem_Eng\Project Files\PPG Industries\Garfield Avenue\30% Design\CADD\DWGS\Cap Break\Design Report\2017-06-20 Cap Break Design Report.dwg Layout: Figure 5-1 User: lam.

Appendix A

Capillary Break Determination for Portions of the Garfield Avenue Group Sites

State of New Jersey

DEPARTMENT OF ENVIRONMENTAL PROTECTION
Site Remediation Program
401 E. State Street, 6th Floor
P. O. Box 028
Trenton, New Jersey 08625-0028
Tel. #(609) 292-1250
Fax. #(609) 777-1914

CHRIS CHRISTIE
Governor

KIM GUADAGNO
Lt. Governor

BOB MARTIN
Commissioner

3/30/17

Ronald J. Riccio, Esq.
Site Administrator
Jersey City PPG Chromium Sites

Re: Capillary Break Determination for Portions of the Garfield Avenue Group Sites
SRP PI Numbers: G000008791, G000008749, 025695, 246332, G000008753, and G000008759

Dear Mr. Riccio:

The New Jersey Department of Environmental Protection (Department) is providing herein its site-specific determination on the placement of a capillary break at the Garfield Avenue Group (GAG) sites within the areas bound by the solid black lines on Figure 1, attached. This determination is consistent with the February 8, 2007 Department Chromium Moratorium memorandum (Chrome Policy) and appropriate Department rules and guidance. This determination is also consistent with the restoration definition in Note 5 on Exhibit 2/3 of the July 29, 2016 revision to the Master Schedule. Furthermore, the Department's determination was based on its evaluation of various key technical submittals made by PPG under the Judicial Consent Order (JCO) as supported by presentations and discussions among the JCO stakeholders. The JCO submittals that support this determination include but are not limited to the following:

- *Final Remedial Action Work Plan (Soil)* (AECOM, April 2012).
- Garfield Avenue Group (GAG) Sites *Restoration Technical Execution Plan* (AECOM, October 2014).
- *Garfield Avenue Capillary Break Re-evaluation* memorandum (AECOM, March 2015).
- *Capillary Rise Technical Execution Plan (AECOM, February 2016).*
- *Capillary Rise Final Report* (AECOM, March 2017).
- *Site-Wide Groundwater Summary Report, April 2015 through March 2016* (AECOM, June 2016).
- *Progress Report for Groundwater Pilot Study and FerroBlack-H Amended Backfill Permits-By-Rule – 2016 Second Quarter (April to June)* (AECOM, July 2016).
- *Progress Report for Groundwater Pilot Study and FerroBlack-H Amended Backfill Permits-By-Rule – 2016 Third Quarter (July to September)* (AECOM, November 2016).
- *Progress Report for Groundwater Pilot Study and FerroBlack-H Amended Backfill Permits-By-Rule – 2016 Fourth Quarter (October to December)* (AECOM, February 2017).

The GAG *Final Remedial Action Work Plan (Soil)* dated April 2012 (RAWP), which was conditionally approved by the Department, requires the installation of a capillary break at the GAG sites. Within the GAG sites *Restoration Technical Execution Plan* dated October 2014, PPG further specified that an impermeable plastic liner would be installed at the GAG sites to serve as the capillary break. However, the Jersey City Redevelopment Agency (JCRA) and Hampshire subsequently expressed concerns that the use of a plastic liner would not be compatible with the plans for future redevelopment of the GAG sites. In response to these stakeholder concerns, PPG prepared the *Garfield Avenue Capillary Break Re-evaluation* memorandum dated March 2015. Based on its evaluation of the *Garfield Avenue Capillary Break Re-evaluation* memorandum, the Department determined that the site-specific alternative(s) to a plastic liner capillary break could be considered contingent upon the completion of further studies.

To formulate the basis and technical approach for this site-specific study to evaluate the protectiveness of capillary break alternatives, a capillary break technical work group was formed with representatives of the JCO parties. The capillary break technical work group collaboratively agreed on a technical scope of work for a study to evaluate various capillary break alternatives, which included an evaluation of the capillary rise within these alternative capillary break materials. The scope of work for the study was then memorialized by PPG in the final *Capillary Rise Technical Execution Plan* dated February 2016. The study was completed in October 2016 and the *"Capillary Rise Final Report"* was submitted by PPG on March 3, 2017 to summarize the study results and conclusions.

Subsequent to its assessment of the aforementioned submittals and related discussions with the JCO stakeholders, the Department has agreed in concept to the location and type of capillary break to be installed by PPG at the GAG sites. The agreed-to conceptual capillary break extents are depicted in Figure 1 within this letter which was originally developed and presented by PPG to the JCO stakeholders on February 16, 2017. The extent of the Department's determination herein applies only to those areas where soil remediation is complete at this time (i.e., areas bound by the solid black lines on Figure 1). The Department cannot make a capillary break determination beyond these designated areas because additional remedial investigation and soil remediation are pending. Based on the information provided by PPG to date and in consideration of the March 8, 2017 correspondence referenced below, the Department has determined that the following would be required for the design of a capillary break within the areas defined in Figure 1:

- The use of 6-inches of certified clean open grade stone (OGS); and
- The bottom of the clean stone must be placed at or above an elevation of 13.2 ft. NAVD88.

PPG may opt to further refine the proposed capillary break extents through the installation and sampling of additional monitoring wells to better understand the extent to which groundwater exceeds the total chromium Department Ground Water Quality Standard (GWQS). In portions of this site where competent meadow mat exists and the total chromium exceeds the GWQS, the meadow mat must be maintained as an engineering control as part of a remedial action permit for groundwater at this site. Similarly, where meadow mat is absent at this site but the backfill has been amended with FerroBlack®-H and is present at the depth meadow mat would have been expected to be present, PPG must demonstrate the Ferro-Black®-H can act in the same manner as the meadow mat, and the amended backfill must be maintained as an engineering control as part of the remedial action permit for groundwater at this site. The remedial action permit for groundwater should also include an evaluation of the need for continued existence of the capillary break as the groundwater remedy progresses. Furthermore, as part of the future capillary break design effort, PPG must consider the unremediated source areas remaining beneath roadways (e.g., Garfield Avenue, Carteret Avenue) and the NJ Transit Hudson-Bergen Light Rail (i.e., Site 199) and their potential to impact the adjacent remediated areas. In portions of the capillary break areas where an impermeable plastic liner is already in place, PPG must evaluate the present condition and determine the future effectiveness of the liner in its current configuration. If the existing impermeable plastic liner is to remain as the final capillary break, the design must specify how the existing liner will be tied in with an OGS capillary break.

On March 8, 2017, the JCRA, the City of Jersey City and Hampshire collectively submitted the *"Restoration Capillary Break/Grading/Stormwater Management Basin Plan Basis of Design"* which provided comments and guidelines for the restoration of the GAG sites. PPG should consider these comments and guidelines in the final capillary break design provided that the final capillary break design remains consistent with the Department's determination herein and protective of human health and the environment. In addition, PPG is to ensure that the final capillary break design complies with all federal, state, and local requirements.

Any refinement of the capillary break areas, supporting design work, capillary break installation, and site restoration must be performed by PPG to meet the October 2017 Restoration Complete milestone per the Master Schedule. The final remediation site grade must be consistent with pre-remedial action conditions unless the capillary break design requires a higher elevation.

If you have any questions regarding this matter, contact me at (609) 984-2905.

Sincerely,

Thomas J. Cozzi, Assistant Director
Site Remediation DEP

C: James D. Ray, Esq.
David Doyle, DEP

Attachment

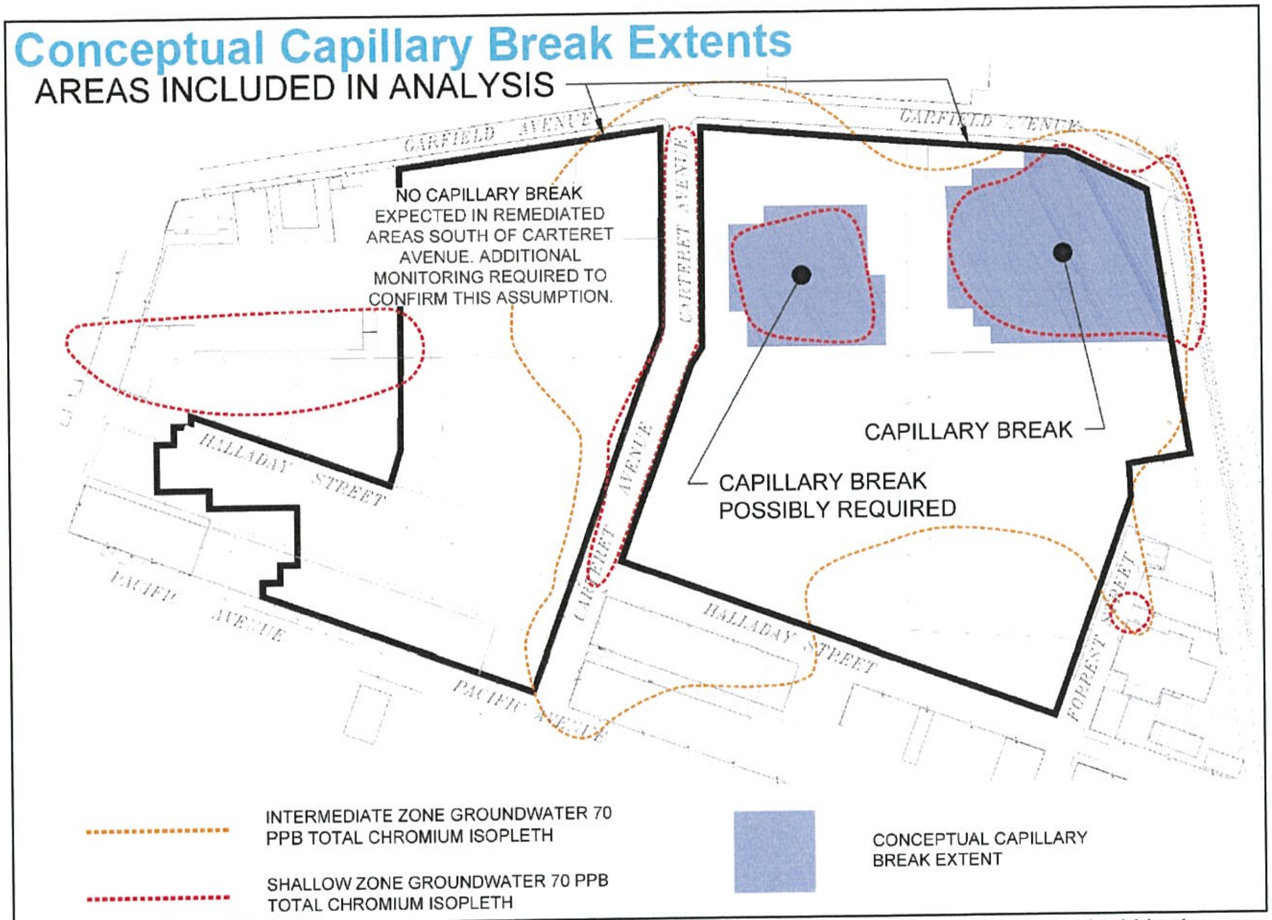


Figure 1: Conceptual capillary break extents for the portions of the Garfield Avenue Group Sites located within the areas outlined by the black solid lines. A determination for areas outside of the areas outlined by the black solid lines is not made at this time because additional remedial investigation and remediation are pending. (Source: AECOM, February 16, 2017 *"Capillary Break Design for Remediated Areas"* presentation to stakeholders).

Appendix B

Laboratory Analytical Reports

(Provided Separately)

Appendix C

Data Validation Reports

(Provided Separately)

Appendix D

List of Boring and Monitoring Well Locations with Competent Meadow Mat Observed

Appendix D
Boring and Monitoring Well Locations with Competent Meadow Mat Observed
Capillary Break Design - Final Report (Revision 2)
PPG, Jersey City, New Jersey

Location ID
10W-F38A
10W-F38A
10W-G32A
10W-G32A
10W-H35A
10W-H35A
10W-H39A
10W-H39A
10W-H41A
10W-H41A
10W-J33A
10W-J35A
10W-J38A
10W-J38A
10W-J39A
10W-J39A
10W-K32A
10W-K32A
10W-K45A
10W-K45A
10W-L37A
10W-L37A
10W-L39A
10W-L39A
10W-L41A
10W-L41A
114-A`6A
114-A`6A
114-A`6A
114-A2A
114-A2A
114-A2A
114-A2A
114-A5A
114-A6A
114-B3A
114-B3A
114-C6A
114-C6A
114-C6A
114-C7A
114-C7A
114-C7A
114CAN15

Appendix D
Boring and Monitoring Well Locations with Competent Meadow Mat Observed
Capillary Break Design - Final Report (Revision 2)
PPG, Jersey City, New Jersey

Location ID
114CAN15
114CAN17
114CAN17
114CAN18
114CAN18
114CAN21
114CAN22
114CAN23
114CAN23
114CAN24
114CAN25
114CAN25
114CAN25
114CAN25
114CAN26
114CAN27
114CAN27
114CAN27
114CAN28
114CAN28
114CAN29
114CAN29
114CAN29
114CAN29
114CAN30
114CAN31
114CAN31
114CAN31
114CAN32
114CAN32
114CAN33
114CAN33
114CAN4
114CAN6
114CAN8
114CAN8
114-D6A
114-D6A
114-D7A
114-D7A
114-D7A
114-E11A
114-E11A
114-E13A

Appendix D
Boring and Monitoring Well Locations with Competent Meadow Mat Observed
Capillary Break Design - Final Report (Revision 2)
PPG, Jersey City, New Jersey

Location ID
114-E13A
114-E13A
114-E13A
114-E1A
114-E1A
114-E2A
114-E2A
114-E3A
114-E3A
114-E5A
114-E5A
114-E5A
114-E6A
114-E6A
114-E6A
114-E7A
114-E7A
114-E9A
114-E9A
114-F0
114-F0
114-F0
114-F10A
114-F10A
114-F11A
114-F11A
114-F12A
114-F12A
114-F12A
114-F13B
114-F13B
114-F13B
114-F13B
114-F13B
114-F14B
114-F14B
114-F4A
114-F4A
114-F6A
114-F6A
114-G0
114-G0
114-G13A
114-G13A

Appendix D
Boring and Monitoring Well Locations with Competent Meadow Mat Observed
Capillary Break Design - Final Report (Revision 2)
PPG, Jersey City, New Jersey

Location ID
114-G6A
114-G6A
114-GWPS-IW1I-PS
114-H0
114-H13A
114-H13A
114-H13B
114-H14B
114-H14B
114-H6A
114-H6A
114-I13A
114-I13A
114-I13B
114-I14B
114-I14B
114-I4A
114-I4A
114-I5A
114-I6A
114-I6A
114-J10A
114-J10A
114-J10A
114-J11A
114-J11A
114-J11A
114-J11A
114-J12A
114-J12A
114-J13B
114-J14B
114-J14B
114-J14B
114-J3A
114-J5A
114-J5A
114-J6A
114-J6A
114-J7A
114-J7A
114-J7A
114-J7A
114-J8A

Location ID
114-J8A
114-J9A
114-J9A
114-J9A
114-L10B
114-L10B
114-L11B
114-L11B
114-L11B
114-L12B
114-L12B
114MON10
114MON11
114MON11
114MON16
114MON24
114MON25
114MON26
114MON27
114MON27
114MON28
114MON28
114MON29
114MON29
114MON30
114MON32
114MON32
114MON32
114MON32
114MON33
114MON9
114MON9
114-MW19B
114-MW19B
114-MW19B
114-MW19B
114-MW19C
114-MW19C
114-MW19C
114-MW19C
114-MW20B
114-MW20B
114-MW20C
114-MW20C

Appendix D
Boring and Monitoring Well Locations with Competent Meadow Mat Observed
Capillary Break Design - Final Report (Revision 2)
PPG, Jersey City, New Jersey

Location ID
114-MW20C
114-MW24B
114-MW2B1-2
114-MW2B1-2
114-MW2B1-3
114-MW2B1-3
114-NW-C8B
114-NW-C8B
114-P1B-MW101I
114-P1B-MW101S
114-P1B-MW101S
114-P1B-MW102I
114-P1B-MW103S
114-P1B-MW103S
114-P1B-MW104S
114-P1C-H13B
114-P1C-J12B
114-P2B1-MW103S
114-P2B1-N0
114-P2B1-N0
114-P2B1-N0
114-P2B1-N10B
114-P2B1-N10B
114-P2B1-N11B
114-P2B1-N11B
114-P2B1-N1B
114-P2B1-N1B
114-P2B1-N2B
114-P2B1-N2B
114-P2B1-N2B
114-P2B1-N3B
114-P2B1-N3B
114-P2B1-N3B
114-P2B1-N4B
114-P2B1-N4B
114-P2B1-N4B
114-P2B1-N5B
114-P2B1-N5B
114-P2B1-N6B
114-P2B1-N6B
114-P2B1-N6B
114-P2B1-N6B
114-P2B1-N7B
114-P2B1-N7B

Appendix D
Boring and Monitoring Well Locations with Competent Meadow Mat Observed
Capillary Break Design - Final Report (Revision 2)
PPG, Jersey City, New Jersey

Location ID
114-P2B1-N8B
114-P2B1-N8B
114-P2B1-N8B
114-P2B1-O14B
114-P2B1-O14B
114-P2B1-O8B
114-P2B1-O8B
114-P2B1-P8B
114-P2B1-P8B
114-P2B1-Q0
114-P2B1-Q0
114-P2B1-Q14B
114-P2B1-Q14B
114-P2B1-Q15B
114-P2B1-Q15B
114-P2B1-Q8B
114-P2B1-Q8B
114-P2B1-R0
114-P2B1-R0
114-P2B1-R14B
114-P2B1-R14B
114-P2B1-R14B
114-P2B1-R8B
114-P2B1-S0
114-P2B1-S0
114-P2B1-S10B
114-P2B1-S10B
114-P2B1-S10B
114-P2B1-S10BR
114-P2B1-S10BR
114-P2B1-S11B
114-P2B1-S11B
114-P2B1-S11BR
114-P2B1-S11BR
114-P2B1-S11BR
114-P2B1-S12B
114-P2B1-S12B
114-P2B1-S13B
114-P2B1-S13B
114-P2B1-S13B
114-P2B1-S13B
114-P2B1-S1B
114-P2B1-S1B
114-P2B1-S8B

Appendix D
Boring and Monitoring Well Locations with Competent Meadow Mat Observed
Capillary Break Design - Final Report (Revision 2)
PPG, Jersey City, New Jersey

Location ID
114-P2B1-S8B
114-P2B1-T11B
114-P2B1-T11B
114-P2B1-U11B
114-P2B1-U11B
114-P2B1-WC-MN01B
114-P2B1-WC-MN01B
114-P2B1-WC-MN10B11B
114-P2B1-WC-MN2B3B
114-P2B1-WC-MN2B3B
114-P2B1-WC-MN6B7B
114-P2B1-WC-MN8B9B
114-P2B1-WC-OP10B11B
114-P2B1-WC-OP2B3B
114-P2B1-WC-OP4B5B
114-P2B1-WC-OP4B5B
114-P2B1-WC-OP6B7B
114-P2B1-WC-OP6B7B
114-P2B1-WC-OP6B7B
114-P2B1-WC-OP6B7B
114-P2B1-WC-OP8B9B
114-P2B1-WC-OP8B9B
114-P2B1-WC-P9B
114-P2B1-WC-P9B
114-P2B1-WC-QR01B
114-P2B1-WC-QR12B13B
114-P2B1-WC-QR12B13B
114-P2B1-WC-QR14B15B
114-P2B1-WC-QR14B15B
114-P2B1-WC-QR2B3B
114-P2B1-WC-QR2B3B
114-P2B1-WC-QR4B5B
114-P2B1-WC-QR4B5B
114-P2B1-WC-QR6B7B
114-P2B1-WC-QR8B9B
114-P2B1-WC-QR8B9B
114-P2B1-WC-S12B15B
114-P2B1-WC-S12B15B
114-P2B1-WC-ST01B
114-P2B1-WC-ST01B
114-P2B1-WC-ST10B11B
114-P2B1-WC-ST10B11B
114-P2B1-WC-ST2B3B
114-P2B1-WC-ST2B3B

Appendix D
Boring and Monitoring Well Locations with Competent Meadow Mat Observed
Capillary Break Design - Final Report (Revision 2)
PPG, Jersey City, New Jersey

Location ID
114-P2B1-WC-ST4B5B
114-P2B1-WC-ST4B5B
114-P2B1-WC-ST8B9B
114-P2B1-WC-ST8B9B
114-P2B1-WC-UV10B11B
114-P2B1-WC-UV10B11B
114-P2B1-WC-UV8B9B
114-P2B2-T10B
114-P2B2-T10B
114-P2B2-V11B
114-P2B2-V6B
114-P2B2-W10B
114-P2B2-W10B
114-P2B2-X6B
114-P2B2-X6B
114-P2B2-X7B
114-P2B2-X8B
114-P2B3-GT-P15A
114-P2B3-GT-P15A
114-P2B3-GT-P15A
114-P2B3-M13A
114-P2B3-MW2
114-P2B3-MW2
114-P2B3-N4A
114-P2B3-N4A
114-P2B3-N6A
114-P2B3-O14A
114-P2B3-O1A
114-P2B3-O1A
114-P2B3-O8A
114-P2B3-O8A
114-P2B3-P8A
114-P2B3-P8A
114-P2B3-Q15A
114-P2B3-Q15A
114-P2B3-Q1A
114-P2B3-Q1A
114-P2B3-R15A
114-P2B3-R15A
114-P2B3-R8A
114-P2B3-R8A
114-P2B3-S12A
114-P2B3-S12A
114-P2B3-S15A

Location ID
114-P2B3-S15A
114-P2B3-S1A
114-P2B3-S1A
114-P2B3-S5A
114-P2B3-S5A
114-P2B3-S5A
114-P2B3-S8A
114-P2B3-WC-MN11A12A
114-P2B3-WC-MN11A12A
114-P2B3-WC-MN5A6A
114-P2B3-WC-MN5A6A
114-P2B3-WC-MN7A8A
114-P2B3-WC-MN7A8A
114-P2B3-WC-MN9A10A
114-P2B3-WC-MN9A10A
114-P2B3-WC-OP13A14A
114-P2B3-WC-OP13A14A
114-P2B3-WC-OP1A2A
114-P2B3-WC-OP1A2A
114-P2B3-WC-OP3A4A
114-P2B3-WC-OP3A4A
114-P2B3-WC-OP5A6A
114-P2B3-WC-OP5A6A
114-P2B3-WC-OP7A8A
114-P2B3-WC-OP7A8A
114-P2B3-WC-QR11A12A
114-P2B3-WC-QR11A12A
114-P2B3-WC-QR13A14A
114-P2B3-WC-QR13A14A
114-P2B3-WC-QR1A2A
114-P2B3-WC-QR1A2A
114-P2B3-WC-QR3A4A
114-P2B3-WC-QR3A4A
114-P2B3-WC-QR5A6A
114-P2B3-WC-QR7A8A
114-P2B3-WC-QR7A8A
114-P2B3-WC-QR9A10A
114-P2B3-WC-QR9A10A
114-P2B3-WC-ST15A16A
114-P2B3-WC-ST15A16A
114-P2B3-WC-ST1A2A
114-P2B3-WC-ST1A2A
114-P2B4-AA10A
114-P2B4-AA10A

Appendix D
Boring and Monitoring Well Locations with Competent Meadow Mat Observed
Capillary Break Design - Final Report (Revision 2)
PPG, Jersey City, New Jersey

Location ID
114-P2B4-AA10A
114-P2B4-AA11A
114-P2B4-AA11A
114-P2B4-AA8A
114-P2B4-AA8A
114-P2B4-AA9A
114-P2B4-AA9A
114-P2B4-AA9A
114-P2B4-AA9A
114-P2B4-BB8A
114-P2B4-BB8A
114-P2B4-BB8A
114-P2B4-MW1
114-P2B4-MW1
114-P2B4-MW102S
114-P2B4-MW102S
114-P2B4-MW2
114-P2B4-MW2
114-P2B4-MW3
114-P2B4-MW3
114-P2B4-U16A
114-P2B4-U16A
114-P2B4-U16A
114-P2B4-U1A
114-P2B4-U1A
114-P2B4-V11A
114-P2B4-V11A
114-P2B4-V13A
114-P2B4-V13A
114-P2B4-V13A
114-P2B4-V15A
114-P2B4-V15A
114-P2B4-V16A
114-P2B4-V16A
114-P2B4-V17A
114-P2B4-V17A
114-P2B4-V17A
114-P2B4-V1A
114-P2B4-V1A
114-P2B4-V1A
114-P2B4-V5A
114-P2B4-V5A
114-P2B4-V8A
114-P2B4-V8A

Appendix D
Boring and Monitoring Well Locations with Competent Meadow Mat Observed
Capillary Break Design - Final Report (Revision 2)
PPG, Jersey City, New Jersey

Location ID
114-P2B4-V8A
114-P2B4-V9A
114-P2B4-V9A
114-P2B4-W15A
114-P2B4-W15A
114-P2B4-W17A
114-P2B4-W17A
114-P2B4-WCAABB9A10A
114-P2B4-WCAABB9A10A
114-P2B4-WC-UV11A12A
114-P2B4-WC-UV11A12A
114-P2B4-WC-UV13A14A
114-P2B4-WC-UV13A14A
114-P2B4-WC-UV15A16A
114-P2B4-WC-UV15A16A
114-P2B4-WC-UV9A10A
114-P2B4-WC-UV9A10A
114-P2B4-WC-WX11A12A
114-P2B4-WC-WX11A12A
114-P2B4-WC-WX7A8A
114-P2B4-WC-WX7A8A
114-P2B4-WC-WX9A10A
114-P2B4-WC-WX9A10A
114-P2B4-WC-YZ11A12A
114-P2B4-WC-YZ11A12A
114-P2B4-WC-YZ13A14A
114-P2B4-WC-YZ13A14A
114-P2B4-WC-YZ15A16A
114-P2B4-WC-YZ15A16A
114-P2B4-X12A
114-P2B4-X12A
114-P2B4-X12A
114-P2B4-X15A
114-P2B4-X15A
114-P2B4-X18A
114-P2B4-X18A
114-P2B4-X3A
114-P2B4-X3A
114-P2B4-Y12A
114-P2B4-Y12A
114-P2B4-Y14A
114-P2B4-Y14A
114-P2B4-Y14A
114-P2B4-Y15A

Appendix D
Boring and Monitoring Well Locations with Competent Meadow Mat Observed
Capillary Break Design - Final Report (Revision 2)
PPG, Jersey City, New Jersey

Location ID
114-P2B4-Y15A
114-P2B4-Y15A
114-P2B4-Y15A
114-P2B4-Y16A
114-P2B4-Y16A
114-P2B4-Y16A
114-P2B4-Y16A
114-P2B4-Y17A
114-P2B4-Y17A
114-P2B4-Y8A
114-P2B4-Z6A
114-P2B4-Z6A
114-P2B4-Z6A
114-RD2-B10A
114-RD2-B10A
114-RD2-B11A
114-RD2-B11A
114-RD2-B12A
114-RD2-B1A
114-RD2-B1A
114-RD2-B5A
114-RD2-B5A
114-RD2-B5A
114-RD2-B8A
114-RD2-B8A
114-RD2-B8A
114-RD2-B9A
114-RD2-B9A
114-RD2-C10A
114-RD2-C10A
114-RD2-C10A
114-RD2-C11A
114-RD2-C11A
114-RD2-C12A
114-RD2-C12A
114-RD2-C13A
114-RD2-C13A
114-RD2-C1A
114-RD2-C1A
114-RD2-C2A
114-RD2-C2A
114-RD2-C3A
114-RD2-C3A
114-RD2-C4A

Appendix D
Boring and Monitoring Well Locations with Competent Meadow Mat Observed
Capillary Break Design - Final Report (Revision 2)
PPG, Jersey City, New Jersey

Location ID
114-RD2-C4A
114-RD2-C4A
114-RD2-C5A
114-RD2-C5A
114-RD2-C6A
114-RD2-C6A
114-RD2-C7A
114-RD2-C7A
114-RD2-C7A
114-RD2-C8A
114-RD2-C8A
114-RD2-C8A
114-RD2-C9A
114-RD2-C9A
114-RD2-C9A
114-RD2-D0
114-RD2-D10A
114-RD2-D10A
114-RD2-D11A
114-RD2-D11A
114-RD2-D12A
114-RD2-D12A
114-RD2-D1A
114-RD2-D1A
114-RD2-D1A
114-RD2-D2A
114-RD2-D2A
114-RD2-D4A
114-RD2-D4A
114-RD2-D5A
114-RD2-D5A
114-RD2-D6A
114-RD2-D6A
114-RD2-D7A
114-RD2-D7A
114-RD2-D8A
114-RD2-D8A
114-RD2-D9A
114-RD2-D9A
114-RD2-E0
114-RD2-E0
114-RD2-E10A
114-RD2-E10A
114-RD2-E11A

Appendix D
Boring and Monitoring Well Locations with Competent Meadow Mat Observed
Capillary Break Design - Final Report (Revision 2)
PPG, Jersey City, New Jersey

Location ID
114-RD2-E11A
114-RD2-E12A
114-RD2-E12A
114-RD2-E2A
114-RD2-E2A
114-RD2-E4A
114-RD2-E4A
114-RD2-E5A
114-RD2-E5A
114-RD2-E6A
114-RD2-E6A
114-RD2-E7A
114-RD2-E7A
114-RD2-F11A
114-RD2-F11A
114-RD2-F1A
114-RD2-F1A
114-RD2-F2A
114-RD2-F2A
114-RD2-F2A
114-RD2-F3A
114-RD2-F3A
114-RD2-F3A
114-RD2-F4A
114-RD2-F4A
114-RD2-F5A
114-RD2-F5A
114-RD2-F6A
114-RD2-F6A
114-RD2-F6A
114-RD2-F7A
114-RD2-F7A
114-RD2-F7A
114-RD2-F8A
114-RD2-F8A
114-RD2-F8A
114-RD2-F9A
114-RD2-F9A
114-RD2-F9A
114-RD2-G0
114-RD2-G0
114-RD2-G10A
114-RD2-G10A
114-RD2-G11A

Appendix D
Boring and Monitoring Well Locations with Competent Meadow Mat Observed
Capillary Break Design - Final Report (Revision 2)
PPG, Jersey City, New Jersey

Location ID
114-RD2-G11A
114-RD2-G11A
114-RD2-G12A
114-RD2-G12A
114-RD2-G1A
114-RD2-G1A
114-RD2-G3A
114-RD2-G3A
114-RD2-G4A
114-RD2-G4A
114-RD2-G4A
114-RD2-G5A
114-RD2-G5A
114-RD2-G6A
114-RD2-G6A
114-RD2-G7A
114-RD2-G7A
114-RD2-G7A
114-RD2-G9A
114-RD2-G9A
114-RD2-G9A
114-RD2-H0
114-RD2-H10A
114-RD2-H10A
114-RD2-H11A
114-RD2-H11A
114-RD2-H12A
114-RD2-H12A
114-RD2-H12A
114-RD2-H1A
114-RD2-H3A
114-RD2-H3A
114-RD2-H4A
114-RD2-H4A
114-RD2-H4A
114-RD2-H5A
114-RD2-H5A
114-RD2-H5A
114-RD2-H5A
114-RD2-H5A
114-RD2-H6A
114-RD2-H6A
114-RD2-H7A
114-RD2-H7A

Appendix D
Boring and Monitoring Well Locations with Competent Meadow Mat Observed
Capillary Break Design - Final Report (Revision 2)
PPG, Jersey City, New Jersey

Location ID
114-RD2-H7A
114-RD2-H8A
114-RD2-H8A
114-RD2-H9A
114-RD2-H9A
114-RD2-I0
114-RD2-I10A
114-RD2-I10A
114-RD2-I10A
114-RD2-I11A
114-RD2-I11A
114-RD2-I11A
114-RD2-I12A
114-RD2-I12A
114-RD2-I1A
114-RD2-I1A
114-RD2-I1A
114-RD2-I2A
114-RD2-I3A
114-RD2-I3A
114-RD2-I3A
114-RD2-I4A
114-RD2-I5A
114-RD2-I5A
114-RD2-I6A
114-RD2-I6A
114-RD2-I7A
114-RD2-I7A
114-RD2-I7A
114-RD2-I8A
114-RD2-I8A
114-RD2-I9A
114-RD2-I9A
114-RD2-J10A
114-RD2-J10A
114-RD2-J10A
114-RD2-J11A
114-RD2-J11A
114-RD2-J3A
114-RD2-J3A
114-RD2-J4A
114-RD2-J4A
114-RD2-J5A
114-RD2-J5A

Appendix D
Boring and Monitoring Well Locations with Competent Meadow Mat Observed
Capillary Break Design - Final Report (Revision 2)
PPG, Jersey City, New Jersey

Location ID
114-RD2-J6A
114-RD2-J6A
114REL13
114REL13
114REL14
114REL14
114REL15
114REL16
114REL17
114REL17
114REL17
114REL18
114REL18
114REL19
114REL20
114REL20
114REL21
114REL21
114REL22
114REL23
114REL23
114REL23
114REL23
114REL24
114REL7
114REL7
114REL8
114REL8
114REL9
114REL9
114REL9
132-B10
132-B10
132-B3
132-B3
132-B4
132-B4
132-B5
132-B5
132-B5
132-B5
132-B6
132-B6
132-B6

Appendix D
Boring and Monitoring Well Locations with Competent Meadow Mat Observed
Capillary Break Design - Final Report (Revision 2)
PPG, Jersey City, New Jersey

Location ID
132-B6
132-B8
132-P3A-B21A
132-P3A-B21A
132-P3A-B22A
132-P3A-B23A
132-P3A-B23A
132-P3A-B24A
132-P3A-B24A
132-P3A-C21A
132-P3A-C21A
132-P3A-C22A
132-P3A-C22A
132-P3A-C24A
132-P3A-C25A
132-P3A-C25A
132-P3A-C27A
132-P3A-C27A
132-P3A-C27A
132-P3A-D21A
132-P3A-D21A
132-P3A-D22A
132-P3A-D22A
132-P3A-D22A
132-P3A-D24A
132-P3A-D24A
132-P3A-D24A
132-P3A-D25A
132-P3A-D25A
132-P3A-D26A
132-P3A-D26A
132-P3A-D27A
132-P3A-D27A
132-P3A-D28A
132-P3A-D28A
132-P3A-D29A-S
132-P3A-E21A
132-P3A-E21A
132-P3A-E22A
132-P3A-E23A
132-P3A-E23A
132-P3A-E24A
132-P3A-E24A
132-P3A-E24A

Appendix D
Boring and Monitoring Well Locations with Competent Meadow Mat Observed
Capillary Break Design - Final Report (Revision 2)
PPG, Jersey City, New Jersey

Location ID
132-P3A-E25A
132-P3A-E25A
132-P3A-E26A
132-P3A-E27A
132-P3A-E27A
132-P3A-E28A
132-P3A-E28A
132-P3A-E29A
132-P3A-E29A
132-P3A-E30A
132-P3A-E30A
132-P3A-F21A
132-P3A-F22A
132-P3A-F22A
132-P3A-F24A
132-P3A-F24A
132-P3A-F24A
132-P3A-F25A
132-P3A-F25A
132-P3A-F26A
132-P3A-F26A

Appendix E

FerroBlack®-H Performance and Longevity Report (Revision 1) and Response to NJDEP/Weston Comments

AECOM
AECOM
30 Knightsbridge Road
Suite 520
Piscataway, NJ 08854

732 564 3600 tel

Memorandum

To	Jody Overmyer, PE, PPG Rich Feinberg, PPG Mark Terril, PPG	Pages	16 + Attachments
CC	Shannon Gleason, PE, AECOM Scott Mikaelian, PE, AECOM Aimee Ruiter, PE, AECOM		
Subject	GW-028: Performance and Longevity Evaluation for Site Wide FerroBlack®-H Amended Backfill Garfield Avenue Group Chromium Sites, Jersey City, New Jersey (Revision 1)		
From	Lucas Hellerich, PhD, PE, LEP, AECOM Sachin Sharma, PE, AECOM Shree Ravi, EIT, AECOM		
Date	June 26, 2017		

1.0 Introduction

At the request of PPG, AECOM has prepared this memorandum to present an evaluation of the performance and longevity of FerroBlack®-H (FB-H) amended backfill at the Garfield Avenue (GA) Group of Sites (the Site).

On May 2, 2017, PPG/AECOM issued the technical memorandum entitled "*GW-028: Performance and Longevity Evaluation for Site Wide FerroBlack®-H Amended Backfill – Garfield Avenue Group Chromium Sites, Jersey City, New Jersey*"; on behalf of the New Jersey Department of Environmental Protection (NJDEP), Weston provided comments to this document on June 2, 2017 via email. This revised submittal provides text, tables (**Tables 1, 2** and **3**), figures (**Figures 1, 2, 3, 4** and **5**) and attachments (**Attachments A, B, C, D, E** and **F**). Additionally, **Attachment G** provides PPG/AECOM responses to the comments received from NJDEP/Weston.

Preliminary findings of the performance of FB-H amended backfill at the Site were summarized in a technical memorandum submitted on July 30, 2015 (AECOM, 2015). This memorandum (provided as **Attachment A**) included a summary of:

- Site conditions based on the groundwater data collected following soil remediation and through March/April 2015; and
- FB-H applications at other sites.

The performance evaluation included in this current memorandum presents:

- An analysis of Site-specific chromium concentrations and geochemical data trends;
- A summary of FB-H applications at other sites; and
- An assessment of the reductive capacity and longevity of FB-H at the Site.

The key conclusions and observations from this evaluation include the following:

- The current (March - September 2016) hexavalent chromium (Cr^{+6}) concentrations in the shallow zone groundwater, where backfill has been amended with FB-H, are less than or equal to the Groundwater Quality Standard (GWQS) of 70 µg/L[1] with the exception of one location (137-P3B-MW102S, Cr^{+6} = 72 µg/L). It is anticipated that, over time, the Cr^{+6} concentrations will continue to decline to less than the GWQS;
- The current (March - September 2016) total chromium (Cr) concentrations in the shallow zone groundwater, where backfill has been amended with FB-H, are less than the GWQS with the exception of four locations in Phases 1B, 2B-1, 3B and 3C. The corresponding Cr^{+6} concentrations in these samples were less than the Cr GWQS of 70 µg/L;
- Persistent reducing conditions are expected to be sustained at the Site in the shallow zone based on the observed geochemical conditions;
- The stoichiometric method of estimating exhaustion of FB-H is more conservative than the bucket-testing approach that was used to develop the dosing of FB-H at the Site. This is because exhaustion of the reducing capacity of the FB-H was not observed during the bucket testing; the test was not conducted to the point where the reductive capacity was exhausted, thereby overestimating the required FB-H. Whereas the stoichiometric method compares the available iron and sulfide (total 7 to 8%) as electron donors on a molar basis to reduce oxygen and Cr^{+6} to Cr^{+3};
- In areas where meadow mat is missing and an upward gradient from the intermediate to the shallow exists, groundwater impacted with Cr^{+6} will react with FB-H. Oxygen from infiltration of precipitation through the shallow zone will also react with FB-H. Based on the stoichiometric demand required to reduce Cr^{+6} and oxygen that may react with the FB-H, the remediated phases at the Site are estimated to have adequate reductive capacity in the shallow zone to last at least 200 years;
- Additionally, the reductive capacity of FB-H is not the only factor in evaluating the longevity of the FB-H. Downward hydraulic gradients, along with the presence of the meadow mat (which acts as a confining layer), should extend the longevity of the FB-H amended backfill by minimizing the extent to which Cr^{+6} from the intermediate zone reacts with the FB-H in the shallow backfill. In areas where the meadow mat is missing and an upward hydraulic gradient (from the intermediate to shallow zone) exists, there is potential for the Cr^{+6} impacted groundwater in the intermediate zone to react with the FB-H present in the shallow zone. Groundwater containing Cr^{+6} may also migrate laterally from adjacent shallow areas that contain chromium-impacted soils (e.g., New Jersey Transit Light Rail area);
- Reduction of Cr^{+6} occurs at the surface of the FB-H particles and the FB-H will continue to serve as a slowly-releasing source of ferrous iron and low concentrations of sulfide over time, extending the longevity of the reducing amendment;
- As mentioned above, Cr^{+6} from the intermediate zone areas with an upward hydraulic gradient where there is no meadow mat will react with FB-H. The only amended phase of the Site where this situation occurs is Phase 1A. Phase 2A (unamended) also has an upward gradient and does not contain the meadow mat; however, Cr and Cr^{+6} concentrations in the shallow and intermediate zones of Phase 2A are less than the GWQS; and

---

[1] The GWQS noted is for Cr, but for the purpose of this evaluation, Cr^{+6} concentrations are compared to the GWQS for Cr.

- Estimates of the longevity of the FB-H amended backfill at amended areas of the Site were developed. Based on these calculations, the FB-H applied at amended areas of the Site is estimated to provide adequate reductive capacity for a period of time ranging between approximately 200 and 16,000 years, depending on the phase. After this period of time, the reductive capacity may be exhausted. These calculations are based on: (1) intermediate zone Cr^{+6} concentrations observed from September 2015 to June 2016, and (2) the dissolved oxygen (DO) values from December 2016.

2.0 FerroBlack®-H Chemistry and Applications

2.1 Mechanism of Action

FB-H is currently being mixed with clean backfill (dense graded aggregate [DGA]) and placed in open excavations at the Site. FB-H is being applied at dosages ranging from 0.7% to 2.8% by weight. The purpose of amending the clean backfill is to prevent recontamination of the clean backfill by groundwater containing Cr^{+6}. As a concurrent benefit, the amended backfill also provides remediation of the shallow groundwater where it is applied. FB-H, a proprietary reagent of Redox Solutions, LLC, is a reductive, colloidal suspension primarily comprised of the following phases, on a percentage by weight basis:

Solid phases	
Iron sulfides	7 - 8%
Other solids	2 - 4%
Soluble phases	
Sulfides	1 - 2%
Other dissolved salts	12 - 13%
Water	73% - 78%

The FB-H is being added to the clean backfill to encourage the aqueous phase reduction of Cr^{+6} to Cr^{+3}, and the subsequent reduction of total Cr concentrations in groundwater through the precipitation out of solution of the Cr^{+3}. This reduction is primarily achieved through a combination of geochemical reactions whereby:

- The soluble sulfide phase (1 - 2% by weight) reacts rapidly with aqueous Cr^{+6}, resulting in its reduction to Cr^{+3}; and

- The solid iron sulfide phase of FB-H (7 - 8% by weight), comprised of ferrous sulfide (FeS) particles, is minimally soluble and provides a longer-term source of both iron and sulfur species to promote reduction of aqueous Cr^{+6} to Cr^{+3} through a combination of dissolution, surface adsorption, and co-precipitation reactions.

Dissolved Phase Reactions

As indicated above, aqueous-phase reduction of Cr^{+6} to Cr^{+3} occurs via two sources of electron donors:

- Sulfides derived from the soluble component of the FB-H; and
- Dissolution of ferrous iron and sulfides from the solid phase FB-H.

Reactions at the Bulk FB-H Particle Surfaces

The series of reactions occurring at the solid FeS particle surface are shown in **Figure 1**. The key driving force behind these multiple reactions is the redox potential of the various species involved.

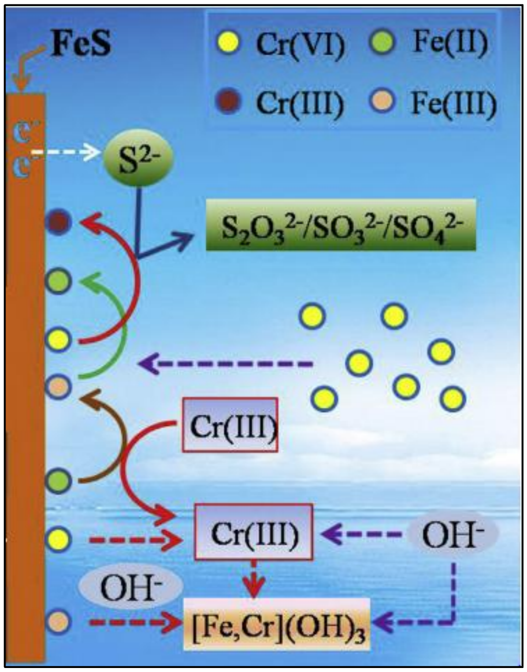
Because the redox potential of FeS ($E^0 = 0.47$ Volts [V] vs. Normal Hydrogen Electrode [NHE]) is lower than that of Cr^{+6}/Cr^{+3} ($E^0 = 1.35$ V vs. NHE), the spontaneous multi-electron transfer from the FeS particle to adsorbed and aqueous phase Cr^{6+} is feasible. Therefore, in-situ reduction of adsorbed and aqueous phase Cr^{+6} to Cr^{+3} would occur simultaneously with the oxidation of Fe^{2+} and S^{2-}, which function as electron donors.

The reduction of Cr^{+6}, predominantly present in the form of chromate oxyanions (CrO_4^{2-}), occurs at the FeS particle surface and results in the formation of various "iron-chromium hydroxides" of the general formula $Fe_xCr_{1-x}(OH)_3$ at pH values greater than 4 (Patterson, et al., 1997; Mullet, et al., 2004; Palmer and Puls, 1994), and/or as precipitates or co-precipitates of Cr^{+3} as $Fe(OH)_3$-$Cr(OH)_3$ (Du, et al., 2016).

The sulfide portion of the FeS particles promote the reduction of Cr^{+6} to Cr^{+3} at the FeS particle surface with the sulfides oxidized initially to elemental sulfur and, again, depending upon the oxidation redox potential of the system, to various polysulfide, $S_2O_3^{2-}$, SO_3^{2-}, or minimal amounts of SO_4^{2-} species.

Over time, any iron species not incorporated into these aforementioned "iron-chromium hydroxides" may form into various iron (oxy)hydroxides (FeOOH), $Fe(OH)_2$, $Fe(OH)_3$, mixed valence iron oxides (e.g., Fe_3O_4,), or iron oxide (FeO) precipitates or co-precipitates depending upon the oxidation redox potential of the system.

Figure 1 - Representation of Cr^{+6} Reduction by the FeS Portion of FB-H (Adapted from Du, et al., 2016)



Redox Transformations within FerroBlack®-H Matrix

One of the unique features of the minimally soluble ferrous iron sulfide particles contained in the FB-H reagent is each particle's ability to maintain its overall charge balance by altering its internal mineral structure. Initially, the ferrous iron sulfide particle structure contains sheets of ferrous (Fe^{2+}) ions that are tetrahedrally coordinated to four sulfide (S^{2-}) ions. This form of ferrous iron sulfide is sometimes referred to as "mackinawite" or "disordered mackinawite".

The Cr^{+6} acceptance of electrons from surface-bound Fe^{2+} (or S^{2-}) causes the oxidation of the surface-bound Fe^{2+} to Fe^{3+} (or S^{2-} to S^0). Even with up to 20% substitution of Fe^{2+} with Fe^{3+}, the mackinawite mineral structure is maintained (Mullet, et al., 2004). It has been shown that the proportion of Fe^{3+} decreases from the surface to the core of the mackinawite crystals (Bourdoiseau, et al., 2008), indicating the transfer of electrons from Fe^{2+} (or S^{2-}) within the particle to the surface. This ability to efficiently transfer electrons from within the mineral structure to the surface causes the retardation of surface passivation of the FeS and, thus, provides a longer-term source of both iron and sulfur species to promote reduction of Cr^{6+} to Cr^{3+}.

2.2 Laboratory studies on FerroBlack®-H

Column testing studies were performed to evaluate the concentrations of leachable Cr^{+6} and oxidation-reduction potential (ORP) levels of chromite ore processing residue (COPR)-containing soil amended with calcium polysulfide and/or FB-H (Brown, et al., 2008). Brown, et al. 2008 is included as **Attachment B**. The reductants were dosed (by weight) between 1 and 7.5 times the concentration of Cr^{+6} in the soil; this range of doses is equivalent to 0.9% to 2.7% (weight of reductant to weight of soils) and is similar to the dose of FB-H being applied at the GA Group sites. Simulated rainwater was passed through the columns over a period of 50 days, simulating the equivalent of 30 to50 years of groundwater flow. After the 50-day simulation, the control test still had soil Cr^{+6} concentrations (2,900 mg/kg), leachable Cr concentrations (2.8 mg/L), and an ORP value (-180 mV) at levels similar to the baseline measurements (3,630 mg/kg, 5 mg/L, and -190 mV, respectively). The treated soil maintained ORP values of less than -400 mv and resulted in no leachable Cr over the period of testing. The testing demonstrated the persistence of reducing conditions of the soils treated with FB-H, and indicated that the reducing capacity of the reductants would not be exhausted, the FB-H reductant would not be passivated, and the reductants would continue to reduce residual Cr^{+6} for at least 30 to 50 years.

2.3 Application of FerroBlack®-H at Other Sites

During discussions with Redox Solutions, LLC. (the vendor of FB-H), AECOM learned that FB-H is currently in use, or has been successfully applied, at five project sites across the country (AECOM, 2015). These sites are listed below.

Site	**Location**	**Contaminant(s) of Concern**	**Matrix**
H&L Plating (former plating site)	Muncie, IN	Cr^{+6}, copper (Cu), arsenic (As), nickel (Ni)	Soil & groundwater
Confidential Global Manufacturing and Industrial Equipment Supplier	York, SC	Cr^{+6}	Soil & groundwater
Heritage Environmental Services (Part B hazardous waste treatment facility)	Indianapolis, IN	mercury (Hg) & Cr^{+6}	Solid waste
CCA Processing Plant (wood preserving facility)	Federalsburg, MD	Cr^{+6}, Cu, & As	Soil & groundwater
Former Manufacturing Plant	Grapevine, TX	Cr^{+6}	Groundwater

The confidential nature of these remediation projects limits the amount of information publicly available, including details about the concentrations of contaminants and the remedial actions performed at these sites. Information about one of these project sites, located in Muncie, IN, is publicly accessible and key observations from this project are summarized below:

- FB-H was applied through injection into the subsurface;
- FB-H was successful in reducing Cr^{+6} concentrations in both soil and groundwater. Pre-remediation concentrations in groundwater ranged from 800,000 ppb – 9,700,000 ppb and were reduced to levels that achieved the cleanup goal of 100 ppb. The concentration of Cr^{+6} in soil was reduced from 3,600 mg/kg to less than 5 mg/kg in the post-treatment samples analyzed;
- Significant reductions in aqueous Cr^{+6} were observed after the first quarter following groundwater injections; and
- Other metals detected at elevated concentrations (arsenic, nickel, antimony) were also remediated using FB-H injections into groundwater along with in situ soil blending.

3.0 Overview of FerroBlack®-H Application at the Site

Backfilling is currently underway at the Site, with varying dosages of FB-H amended fill already placed in several areas of Site 114, including Phases 1A, 1B, 1C, 2B-1, 2B-2, 2B-3, 2B-4, 3A, 3B, and 3C. The amount of FB-H placed within each phase is discussed in **Section 4.0**. Groundwater monitoring wells have been installed in areas where excavation and backfilling have been completed in order to monitor groundwater quality following soil remediation. Following their installation, these wells are sampled on a quarterly basis (minimum of four rounds in accordance with the approved Site-wide amended backfill Permit-By-Rule [PBR]) for analytes including Cr^{+6}, Target Analyte List (TAL) metals (including total Cr), pH, ORP, and sulfur species. The pre- and post-remediation shallow groundwater monitoring network is shown on the attached **Figure 2** along with dosages of the FB-H amendment across the Site. Additional soil remediation will be conducted in Phase 3B South, roadways, and other areas. The FB-H PBR groundwater monitoring well network is shown on **Figure 3.** Additional wells will be installed in the Phase 3B South excavation areas once the excavation is completed and backfilled.

4.0 Evaluation of FerroBlack®-H Performance

4.1 Chromium and Hexavalent Chromium

Following the excavation of impacted soils and their replacement with FB-H amended clean backfill, Cr^{+6} and Cr concentrations in shallow zone groundwater have reduced compared to historical (pre-remediation) levels. These concentration reductions are related to the excavation of impacted soils and the establishment of geochemically reducing conditions induced by the application of FB-H. Geochemical reducing conditions are characterized by low DO (less than 1 mg/L), negative ORP, and the presence of reductants (i.e., ferrous iron and sulfide). Site geochemical conditions are discussed in **Section 4.2**.

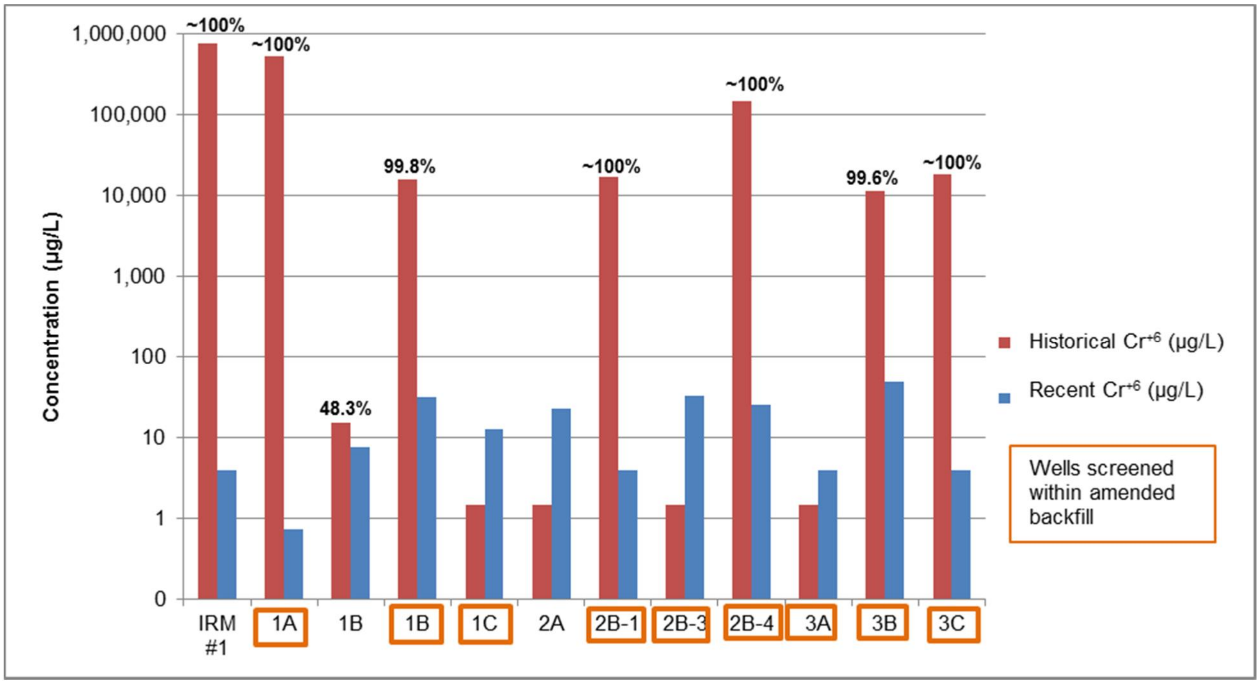
The most recent Cr and Cr^{+6} analytical data in the shallow and intermediate zone collected from the PBR monitoring wells are summarized in **Table 1**. The data was collected between March and September 2016 and was previously presented in the *Progress Report for Groundwater Pilot Study and FerroBlack®-H Amended Backfill Permits-By-Rule – 2016 Fourth Quarter* (AECOM, 2017a). This data can be summarized as follows:

- The shallow zone concentration of Cr^{+6} in areas where the FB-H amendment has been applied is less than the Cr GWQS of 70 µg/L in 20 of 22 wells. Compared to historical (pre-remediation) conditions, this represents a concentration decrease of nearly 100% (**Figure 4**).
- The concentration of Cr^{+6} was equal to or marginally greater than the GWQS of 70 µg/L in two shallow wells screened within amended fill (114-P2B4-MW103S [Cr^{+6} = 70 µg/L] and 137-P3B-MW102S [Cr^{+6} = 72 µg/L]). These concentrations are expected to reduce further with time.

- The Cr concentration in the shallow zone groundwater in amended phases of the Site was less than the GWQS in 18 of 22 wells, with a median concentration of 18.7 µg/L. This represents a concentration reduction of approximately 86% to nearly 100% in areas where the pre-remediation Cr was greater than the GWQS (**Figure 5**).

  The concentration of Cr in four wells located within amended areas was greater than the GWQS of 70 µg/L. These wells are 114-P1B-MW102S (Phase 1B), 114-P2B1-MW102S (Phase 2B-1), 137-P3B-MW101S (Phase 3B), and HSS-P3C-MW1S (Phase 3C). The corresponding Cr^{+6} concentrations in these samples were less than 70 µg/L. This suggests that the Cr present in the subsurface at these locations will precipitate out of the groundwater and gradually decrease to meet the GWQS.

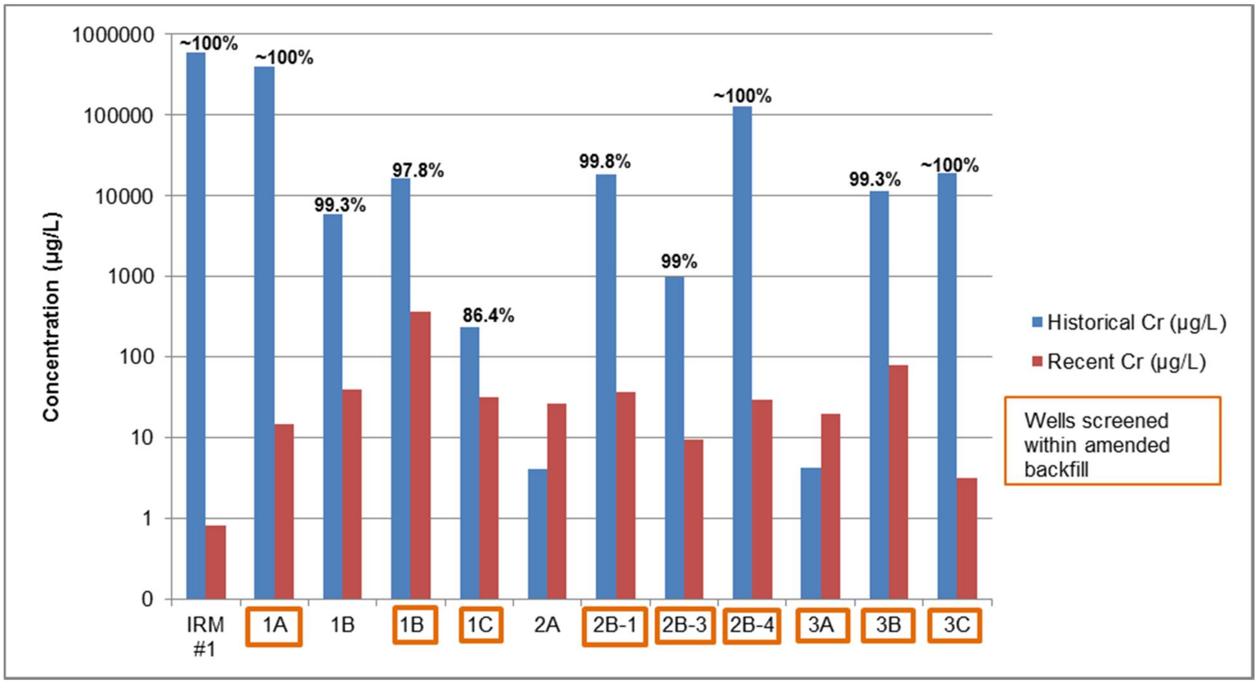
Figure 4 Comparison of Pre- and Post-remediation Cr^{+6} Concentrations in the Shallow Zone



Notes:

1) *Percentage decreases in concentrations are shown only where pre-remediation concentrations were greater than the post-remediation concentrations.*
2) *Concentrations are based on analytical results obtained between March and September 2016 (Table 2).*
3) *For Phase 3A, the detection limit of Cr^{+6} in the post-remediation sample was greater than the pre-remediation sample. Cr^{+6} was less than 70 µg/L in both events. For Phase 1C, the historical result was less than the detection limit; the current Cr^{+6} concentration of 13 µg/L is a detected result.*

Figure 5 **Comparison of Pre- and Post-remediation Cr Concentrations in the Shallow Zone**



Notes:

1) *Percentage decreases in concentrations are shown only where pre-remediation concentrations were greater than the post-remediation concentrations.*
2) *Concentrations are based on analytical results obtained between March and September 2016 (Table 2).*

Compared to pre-remediation conditions, there has been a significant improvement in groundwater quality with respect to Cr and Cr^{+6} concentrations upon the application of FB-H. The continued downward trends in Cr^{+6} concentrations indicate the persistence of reducing conditions in the shallow zone and the longevity of the amendment.

4.2 Geochemistry

Geochemically reducing conditions are required for the reduction of Cr^{+6} to Cr^{+3}. The addition of the FB-H amendment to the shallow zone changes the shallow groundwater geochemistry by creating a reducing environment, leading to the conversion of Cr^{+6} to Cr^{+3}, followed by subsequent precipitation of Cr out of the groundwater in the form of Cr^{+3} hydroxides. A discussion of the data for geochemical parameters affecting the reduction of Cr^{+6} is presented below. The data was collected between March and September 2016 and was previously presented in the Progress Report for Groundwater Pilot Study and FerroBlack®-H Amended Backfill Permits-By-Rule – 2016 Fourth Quarter (AECOM, 2017a).

pH

- In the shallow zone where backfill was amended with FB-H, pH ranged from 5.78 s.u. to 7.65 s.u., with a median pH of 6.77 s.u., with the exception of one well (MW-Morris 1A in Phase 1A, pH = 11.07 s.u.).
- In the unamended areas of the Site, pH in the shallow groundwater was greater than in the amended areas, ranging from 6.52 s.u. to 11.32 s.u., with a median pH of 10.35 s.u. These higher pH observations are consistent with pre-excavation conditions (approximately 12 s.u.) and will continue to be monitored.

- In areas where FB-H has been applied, an overall downward trend in the pH has been observed. The pH values have stabilized at near neutral pH levels.
- The reductions in groundwater pH are being driven by the oxidation of FeS in the FB-H, which generates acidity. The post-remediation average pH values indicate overall near-neutral conditions at the Site that are conducive to the formation of reduced chromium complexes (e.g., $Fe_xCr_{1-x}(OH)_3$ and $Fe(OH)_3$-$Cr(OH)_3$).

ORP

- ORP in the shallow zone groundwater samples collected from wells located in FB-H amended areas of the Site was less than 0 mv (i.e., reducing range) in 20 of the 21 wells. The median ORP of these samples was -88.5 mv.
- In unamended areas of the Site, shallow groundwater ORP was greater, with a median value of 3.2 mv. ORP was less than 0 mv in four of nine wells.
- Although ORP can vary over time and is only one of the indicator parameters for a reducing environment, these ORP values indicate that reducing conditions exist in the shallow groundwater. Other geochemical measurements support that reducing conditions are present in the shallow groundwater at the Site. For example, DO levels in amended areas are less than 1 milligram per liter (mg/L) (discussed below).

Dissolved Oxygen

- The DO content of the groundwater samples collected from the shallow wells located in FB-H amended areas of the Site was less than 1 mg/L in 16 of the 21 wells. The DO in these samples ranged from 0.02 mg/L to 2.4 mg/L, with a median value of 0.48 mg/L.
- In unamended areas of the Site, DO content of the shallow groundwater ranged from 0.07 mg/L to 1.7 mg/L in nine monitoring wells. The median DO concentration in these samples was 0.24 mg/L.
- DO was low in the intermediate zone groundwater samples as well, mostly less than 1 mg/L, with a median value of 0.49 mg/L. The maintenance of low DO in both the shallow and intermediate zone groundwater is conducive to the long-term performance of FB-H in areas where an upward hydraulic gradient exists.

Sulfates and Sulfides

Sulfide was expected to be present in amended soils and in groundwater because it is a soluble component of FB-H. It was expected that the soluble sulfide would oxidize rapidly to sulfate or elemental sulfur. Total (unfiltered) sulfide in the shallow amended zone was less than the method detection limit in 18 of the 22 wells. The maximum sulfide concentration (unfiltered) was observed in Phase 1A, where the sample from MW-Morris 1A (March 2016) contained 80 mg/L of the analyte. Head space readings of hydrogen sulfide (H_2S) in the monitoring wells were observed to be 0 parts per million (ppm) at most of the locations during this timeframe.

Sulfide levels in groundwater have declined over time; it is anticipated that this trend will continue as sulfide reacts with Cr^{+6} and other oxidizing agents such as oxygen. However, the FB-H will continue to serve as a slowly releasing source of ferrous iron and low concentrations of sulfide over time, extending the longevity of the reducing amendment.

Pre-remediation sulfate concentrations in the shallow groundwater ranged from non-detect to 5,480 mg/L (only three samples were tested with two non-detected results with a detection limit of 2 mg/L). Post-remediation sulfate concentrations range from 166 to 4,050 mg/L, with a median concentration of 1,475 mg/L. This indicates that there is no widespread increase in sulfate concentrations following soil remediation.

4.3 Non-Chromium Target Analyte List (TAL) Metals

In groundwater samples collected from historical monitoring wells prior to the soil remediation, exceedances of several TAL metals were reported, including aluminum (Al), As, antimony (Sb), beryllium (Be), lead (Pb), Ni, thallium (Tl), and vanadium (V). Following the completion of soil remediation in these areas, the concentrations of several of these TAL metals (including Sb, As, Ni, and Tl) have reduced compared to historical levels. Following placement of the amended backfill, the concentrations of the Chromate Chemical Production Waste (CCPW) metals (Sb, Cr, Ni, Tl, V) have steadily declined in the shallow zone groundwater. The concentration of iron (Fe) increased following the placement of the amended backfill.

The expected reduction of several TAL metals at many locations is a beneficial result of the formation of metal sulfide precipitations, and co-precipitation as a part of ferric oxyhydroxide formation. Typically, Al and As are co-precipitated with ferric oxyhydroxide, and Sb and V are precipitated as metal sulfides. While Al, As, Mn, and Pb are still detected at concentrations exceeding their respective GWQS at certain locations, it is anticipated the concentrations of these metals will decline over time. Concentrations of Sb, Ba, Cu, Hg, Se, Tl, and Zn have already decreased to levels less than the GWQS. Although some of these metals are redox sensitive, their concentrations are less than those of Cr^{+6}; therefore, their presence in the subsurface is not expected to affect the performance of the amendment.

4.4 FerroBlack®-H Performance Evaluation Summary

The performance of FB-H was evaluated using Site shallow groundwater conditions. A summary of the shallow zone groundwater conditions is provided in the attached **Table 2**. The following factors are summarized in **Table 2** for each amended area of the Site:

- Dosages of FB-H;
- Concentration ranges for Cr^{+6} and Cr;
- Geochemical conditions (pH, ORP, DO);
- Presence of reducing conditions, including the presence of sulfide; and
- TAL metal concentrations.

Overall, the performance evaluation indicates persistent reducing conditions in the shallow zone which have resulted in decreases of Cr^{+6} and Cr concentrations compared to pre-soil remediation conditions. These reducing conditions include near-neutral pH (6 - 8 s.u.), negative ORP values, and low DO (< 1 mg/L). Under near-neutral pH conditions, the kinetics of re-oxidation of Cr^{+3} to Cr^{+6} are extremely slow, and are limited by the poor solubility of Cr^{+3} hydroxide and iron-chromium hydroxide solids (Eary and Ral, 1987). Because Cr^{+3} can only re-solubilize from the precipitate phases at an extremely low rate, it will not be present in the aqueous phase for the re-oxidization to occur. Additionally, the redox state can be transient and vary over small distances; therefore, reduction can occur in micro niches or in other cases within the areas exhibiting oxidizing conditions based on these measurements.

In addition to reducing chromium concentrations, the application FB-H has resulted in the reduction of the concentrations of TAL metals. Persistent reducing conditions are expected to be sustained at the Site in the shallow zone based on the observed geochemical conditions and the amount of FB-H that has been added. The FB-H mineral matrix will continue to provide a slow-release, long-term source of ferrous iron and low levels of sulfide in the subsurface, which will continue to decrease Cr^{+6} and TAL metals concentrations.

5.0 FerroBlack®-H Longevity Assessment

Calculations of the expected longevity of the applied amendment in each of the excavation phases are presented in **Attachment C**. The calculations were performed to evaluate if the applied FB-H is sufficient to sustain reducing conditions in the subsurface for an extended period of time. In order to provide conservative estimates, the lowest dosage of FB-H in each of the amended phases was considered in this evaluation. The following phase-specific variables were considered:

- Groundwater flow and vertical hydraulic gradients (based on field testing data collected between June and December 2016);
- Surface areas;
- DO in groundwater and rainwater infiltration;
- Cr^{+6} in the intermediate zone soil and groundwater;
- Cr^{+6} from the adjacent CCPW-impacted area (may migrate through openings in the sheet pile);
- Cr^{+6} present in the water in the open excavation that may react with FB-H at the time of backfill placement; and
- FB-H dosage (% by weight) and total amount of FB-H applied to clean backfill.

With the exception of Phases 1A, 2A, and 2B-2, the remaining phases at the Site are adjacent to residual CCPW source areas. There is potential for groundwater to migrate horizontally from the residual CCPW source areas to the adjacent IRM #1 area and Phases 1B, 1C, and 2B-1, if there is leakage through, or flow around, the sheet pile. If the Cr^{+6} from these adjacent CCPW source areas migrates into the FB-H amended areas, the longevity of the FB-H may be reduced. The current estimates of the longevity include the flux of Cr^{+6} from these adjacent CCPW areas, wherever applicable. It was observed that a horizontal gradient (0.01 ft/ft) exists from the adjacent CCPW area (light rail) to the Phase 1C area. The flux of Cr^{+6} from this adjacent CCPW area is included in the calculations.

The calculations performed for estimating FB-H longevity assumed exhaustion of FB-H in the backfill could result primarily from:

1) Presence of Cr^{+6} and oxygen in the intermediate zone soil and groundwater, coupled with an upward hydraulic gradient and absence of meadow mat; and
2) Oxygen contained in infiltrating rainwater.

The assessment process consisted of the following steps:

- Evaluating the horizontal hydraulic conductivity of the intermediate zone within each phase based on the previous testing (pump tests and slug tests) conducted at the Site. The hydraulic conductivity values used for each phase are provided as **Attachment D**. The vertical hydraulic conductivity values were based on the observed horizontal conductivity values and were used in computing vertical downward flowrates;
- Evaluating the hydraulic gradients within each phase based on the data collected from the transducers currently deployed within shallow and intermediate zones at the Site. If downward hydraulic gradients are present, Cr^{+6} will be inhibited from migrating from the intermediate zone into the shallow zone and reacting with the FB-H;
- Assessing the presence of an adjacent, residual CCPW source area and determining if groundwater is migrating from the residual CCPW source area towards the amended shallow zone. If an adjacent residual CCPW source is present and is migrating towards the amended shallow zone, then Cr^{+6} from the residual source area will react with the FB-H;

- Estimating the average concentrations of Cr^{+6} and DO in the intermediate zone;
- Estimating the average pre-remediation concentrations of Cr^{+6} in the shallow zone in different areas;
- Estimating the amount of rainfall that could infiltrate into the shallow zone, and estimating a corresponding DO value based on the average DO in an amended shallow zone area on the Site. An average of the DO concentrations from the shallow zone of Phase 2A from December 2016 was used in these estimates since this area is excavated and backfilled with unamended DGA and provides the most representative snapshot of background DO conditions in the shallow zone of the Site. Additionally, Cr and Cr^{+6} concentrations in the shallow and intermediate zones in this phase are less than the GWQS. The amount of infiltration at the Site was computed based on the hydrologic evaluation of landfill (HELP) model and is provided as **Attachment E**;
- Calculating the fluxes of Cr^{+6} from the intermediate zone into the shallow zone, and from the adjacent CCPW source areas to the shallow zone;
- Calculating the fluxes of DO from the intermediate zone into the shallow zone, and from the infiltration of rainwater into the shallow zone;
- Assessing the required amount of FB-H based on a stoichiometric demand of the amount of Cr^{+6} and oxygen that will react with FB-H. The stoichiometric calculations include the demand exhibited by both Cr^{+6} and oxygen (present as DO or from precipitation). The stoichiometric calculation for Cr^{+6} and oxygen are provided as **Attachment F**;
- Estimating the longevity of the existing FB-H that has been amended to each phase for providing reductive capacity of the Cr^{+6} and DO fluxing into each phase; and
- Estimating the minimum thickness of FB-H for each phase to provide reductive capacity for 30 and 100-year timeframes.

Based on this evaluation, the following observations and predictions can be made:

- The excavation phases of the Site where FB-H is used as the backfill amendment have sufficient quantity of the reductant to maintain reducing conditions and reduce Cr^{+6} in the shallow zone for a minimum of approximately 200 years;

- The reductive capacity of FB-H is not the only factor in evaluating the longevity of the FB-H. Downward hydraulic gradients and the presence of the meadow mat (as a barrier) should extend the longevity of the FB-H amended backfill since these characteristics should minimize the interaction of Cr^{+6} from the intermediate zone with the reductants in the FB-H. Where there are upward hydraulic gradients, and the confining layer (meadow mat) is absent, there is potential for the interaction of Cr^{+6} with the FB-H;

- Meadow mat is not present in Phase 1A and Phase 2B-2. Although groundwater flow is generally downward at the Site, upward hydraulic gradients have been temporarily observed (for periods ranging from days to months) in certain areas (Phases 1A, 1B, 2B-1, 2B-2, 2B-3 and 2B-4). Additionally, there will be other oxidizing constituents (e.g., oxygen) that could react with the FB-H. However, given the low concentrations of DO (< 1 mg/L, generally) in amended areas in shallow zone, it is anticipated that the Cr^{+6} from the intermediate zone and oxygen present in the infiltrating rainwater will be the primary factors contributing to the depletion of FB-H; and

- At Phase 3C, the hydraulic gradients are observed to be always upward potentially due to the relatively recent excavation and groundwater dewatering operations at Phase 3C than other locations at the Site.

The longevity estimates were developed based on available data, under the following key assumptions:

- The annual Cr^{+6} groundwater flux is constant and is based on the most current groundwater and soil concentration data. The calculation does not account for groundwater concentration decreases due to dispersion, dilution, shallow zone source removal, and active treatment of shallow groundwater. These would reduce the flux of Cr over time;
- The upward migration of Cr^{+6} in groundwater is subject to retardation; which is estimated from the apparent partitioning calculated as the ratio of the soil and aqueous Cr concentrations; and
- The vertical hydraulic conductivity is assumed to be 10% of the horizontal hydraulic conductivity (Todd, 1980).

6.0 Conclusions and Observations

Based on the evaluation presented above, the following conclusions can be drawn relative to the performance of FB-H at the Site:

- The most recent sampling data obtained from shallow wells at the Site indicate that Cr and Cr^{+6} are at reduced levels compared to pre-excavation conditions. Any exceedances of the Cr GWQS are expected to reduce further over time as the Cr continues to precipitate out of the groundwater;
- Cr^{+6} reduction has been achieved at other sites through the application of FB-H coupled with a reducing geochemical environment, including very low levels of DO, and negative ORP. Successful remediation of other metals such as antimony, arsenic, and nickel has also been achieved with this technology, in both soil and groundwater;
- pH conditions in groundwater following placement of the amended backfill are conducive to the formation of Cr^{+3} precipitates;
- Negative ORP and low DO (< 1 mg/L) conditions exist and are expected to be sustained in the amended shallow zone. Following placement of the amended backfill, ORP is negative (less than 0 mv) and Cr^{+6} and Cr concentrations are either less than the reporting limit of 10 µg/L (for both) or their concentrations are continuously declining;
- The post-remediation shallow zone groundwater analytical data indicate exceedances of the GWQS for several TAL metals as discussed in Section 4.3. However, compared to the pre-remediation levels, current TAL metal concentrations in the groundwater have decreased as the shallow soil has been excavated and backfilled with DGA. Although some of these metals are redox sensitive, their concentrations are lower than that of Cr^{+6}; therefore, their presence in the subsurface is not expected to affect the performance of the amendment;
- Sulfide levels in groundwater have declined over time. It is anticipated that the sulfide levels in groundwater should continue to decline over time as sulfide reacts with Cr^{+6} and other oxidizing agents, such as oxygen;
- Reduction of Cr^{+6} occurs at the surface of the FB-H particles and the FB-H should continue to serve as a slowly releasing source of ferrous iron and low concentrations of sulfide over time, extending the longevity of the reducing amendment;
- The stoichiometric method of estimating exhaustion of FB-H is more conservative than the bucket testing approach that was used to develop the dosing of FB-H at the Site. This is because exhaustion of the reducing capacity of the FB-H was not observed during the

bucket testing; the test was not conducted to the point where the reductive capacity was exhausted, thereby overestimating the required FB-H. Whereas the stoichiometric method compares the available iron and sulfide (total 7 to 8%) as electron donors on a molar basis to reduce Cr^{+6} to Cr^{+3};

- Based on the stoichiometric demand of Cr^{+6} and oxygen, the amended phases of the Site are estimated to have sufficient FB-H applied to maintain reducing conditions for a minimum of approximately 200 years (**Table 3**); and
- The reductive capacity of FB-H is not the only factor in evaluating the longevity of the FB-H. Downward hydraulic gradients and presence of the meadow mat should extend the longevity of the FB-H amended backfill since these characteristics should minimize the amount of Cr^{+6} reacting with the FB-H.

7.0 References

AECOM, 2015. GAG-004F: FerroBlack–H Studies Status Memorandum. July 2015.

AECOM, 2017a. Progress Report for Groundwater Pilot Study and FerroBlack®-H Amended Backfill Permits-By-Rule – 2016 Fourth Quarter (AECOM, 2017a). February 2017.

Bourdoiseau, et al., 2008. Bourdoiseau, J.-A., Jeannin, M., Sabot, R., Rémazeilles, C and Refait, Ph. 2008. Characterisation of Mackinawite by Raman Spectroscopy: Effects of Crystallisation, Drying and Oxidation. Corrosion Science , 50: 3247 – 55.

Brown, et al., 2008. Brown, Richard, Leland Carlblom, Rick Jacobs, and Gordon Post, 2008. In-situ Chemical Reduction of Hexavalent Chrome at Chromite Ore Processing Residue Sites. *Sixth International Battelle Conference.* May 2008.

Du, et al., 2016. Du, Jiangkun, Jianguo Bao, Chenghang Lu, and David Werner, 2016. Reductive Sequestration of Chromate by Hierarchical FeS@Fe0 Particles. *Water Research* 102 (2016): 73-81. October 2016.

Eary, L. Edmond and Dhanpat Ral, 1987. *Kinetics of Chromium (III) Oxidation to Chromium (IV) by Reaction with Manganese Dioxide.* Environmental Science and Technology, vol. 21, p 1187-1193. December 1987.

Mullet, et al., 2004. Mullet, Martine, Sophie Boursiquot, and Jean-Jacques Ehrhardt, 2004. Removal of hexavalent chromium from solutions by mackinawite, tetragonal FeS. *Colloids and Surfaces A: Physiochemical and Engineering Aspects* 244(1):77-85. September 2004.

New Jersey Department of Environmental Protection (NJDEP), 2015. Discharge Approval and Monitoring Requirement Associated with Permit-By-Rule Discharge Authorization for PPG Industries (COPR). April 2015.

Palmer, Carl D., and Robert W. Puls, 1994. Natural Attenuation of Hexavalent Chromium in Groundwater and Soils, *EPA Groundwater Issue*. October 1994.

Patterson, et al., 1997. Patterson, Ronald R, Scott E. Fendorf, and Mark Fendorf, 1997. Reduction of Hexavalent Chromium by Amorphous Iron Sulfide. *Environmental Science & Technology* 31, No. 7: 2039-2044. June 1997.

Todd, D.K., 1980. Groundwater Hydrogeology (2nd edition). Wiley, New York. 552 pp.

List of Tables, Figures, and Attachments

Tables

Figures (not embedded in text of memorandum)

Attachments

Tables

Table 1
Summary of Chromium and Hexavalent Chromium Concentrations
Shallow and Intermediate Zone Groundwater
Garfield Avenue Group of Sites
PPG, Jersey City, New Jersey

Well ID	Sample Date	Total Cr (µg/L)	Cr^{+6} (µg/L)
Shallow Zone			
114-MC-MW101S	6/22/2016	14.3 J	17 RA
114-MC-MW102S	6/24/2016	5.8 J	18 J
114-P1A-MW101S	9/16/2016	< 0.81 U	< 3.9 U
114-P1B-MW101S	6/21/2016	39.2 J	7.8 J
114-P1B-MW102S	9/16/2016	**366**	32 J
114-P1B-MW103S	6/22/2016	9.5 JB	< 3.9 RA
114-P1B-MW104S	6/21/2016	56.4	8.8 J
114-P1C-MW101S	6/20/2016	32.2	13 RA
114-P2A-MW101S	9/14/2016	4.1 J	< 3.9 U
114-P2A-MW102S	9/27/2016	7.0 J	10
114-P2A-MW103S	9/15/2016	26.8	23 JB
114-P2A-MW104S	9/15/2016	< 0.81 U	< 3.9 UB
114-P2B1-MW101S	6/20/2016	37.5	< 3.9 RA
114-P2B1-MW102S	6/23/2016	**484**	< 3.9 RA
114-P2B1-MW103S	6/23/2016	43.9	19 RA
114-P2B2-MW101S	6/20/2016	19.3	13 RA
114-P2B3-MW101S	6/22/2016	9.5 JB	33 RA
114-P2B4-MW101S	6/21/2016	29.3 J	26
114-P2B4-MW102S	6/21/2016	18.1 J	24 J
114-P2B4-MW103S	6/22/2016	16.1 JB	**70 RA**
132-P3A-MW102S	6/17/2016	27.2	< 3.9 U
132-P3A-MW103S	6/16/2016	6.6 J	4.3 J
132-P3A-MW104S	6/16/2016	1.7 J	< 3.9 U
133-P3C-MW101S	9/13/2016	3.2 J	< 3.9 RA
133-P3C-MW102S	9/13/2016	10.6	< 3.9 RA
137-P3B-MW101S	6/15/2016	**78.8**	50
137-P3B-MW102S	6/15/2016	< 16 UJ	**72 J**
143-P3A-MW101S	6/20/2016	20.0	< 3.9 RA
HSS-P3C-MW1S	6/17/2016	**1050**	15
HSS-P3C-MW2S	6/16/2016	26.3	< 3.9 U
MW-MORRIS 1A	3/21/2016	14.6	< 0.74 UJ
Intermediate Zone			
114-MC-EW103	6/23/2016	**388**	< 3.9 RA
114-MC-PZ103	6/23/2016	**15000**	< 3.9 RA
114-MC-PZ203	6/23/2016	**215000**	**188000 RA**
114-P1A-MW101I	6/17/2016	**8710**	**7700**
114-P1B-MW101I	6/21/2016	**149000**	**117000**
114-P1B-MW102I	9/16/2016	**541000**	**566000**
114-P1C-EW1	6/18/2015	**12800 J**	**13600 J**
114-P1C-PZ1	9/12/2016	**1620**	**1300**
114-P1C-PZ2	9/12/2016	**615**	**200 J**
114-P1C-MW101I	6/20/2016	**6230**	**5100 RA**
114-P2A-MW101I	9/14/2016	12.4	17
114-P2A-MW102I	9/14/2016	8.8 J	16
114-P2A-MW103I	9/15/2016	7.2 J	< 3.9 UB
114-P2A-MW104I	9/15/2016	4.0 J	< 3.9 UB
114-P2B1-MW101I	6/20/2016	**1320000**	**891000 RA**
114-P2B2-MW101I	6/20/2016	**473000**	**403000 RA**
114-P2B3-MW101I	6/22/2016	**142000 J**	**136000 RA**
114-P2B4-MW101I	6/21/2016	**224000**	**142000 J**
114-P2B4-MW102I	6/21/2016	**16200 J**	**15300**
114-P2B4-MW103I	6/22/2016	9.2 JB	9.3 RA
132-P3A-MW102I	6/17/2016	10.2 J	21 J
132-P3A-MW103I	6/16/2016	**20900 J**	**21700**
132-P3A-MW104I	6/16/2016	1.5 J	< 3.9 U
133-P3C-MW101I	9/13/2016	2.9 J	< 3.9 RA
133-P3C-MW102I	9/13/2016	1.8 J	< 3.9 RA
137-P3B-MW101I	6/24/2016	**140**	< 3.9 U
137-P3B-MW102I	6/15/2016	1.5 J	< 3.9 U
143-P3A-MW101I	6/20/2016	**10700**	**9800 RA**

Notes:

1) Analytical data from the most recent sampling date for each well is shown.
2) **Bold** - Indicates exceedance of NJDEP's GWQS for Cr (70 µg/L).
3) Data presented is from the analysis of unfiltered groundwater samples.

Cr - chromium
Cr^{+6} - hexavalent chromium
GWQS - Groundwater Quality Standard
NJDEP - New Jersey Department of Environmental Protection
µg/L - micrograms per liter
🟩 - shallow well screened within FerroBlack®-H amended backfill

Qualifier Definitions:

J - Indicates the result was an estimated value; the associated numerical value was an approximate concentration of the analyte in the sample.

JB - The analyte concentration is greater than three times, but less than or equal to ten times the concentration in the associated method blank. The presence of the analyte in the sample is considered real; the concentration is quantitatively qualified (JB) due to method blank contamination.

U - Indicates the analyte was not detected in the sample above the sample reporting limit.

UB - The analyte concentration is less than or equal to three times the concentration in the associated method/prep blank. The presence of the analyte in the sample is negated (UB) due to laboratory contamination.

UJ - Indicates the analyte was not detected above the reporting limit and the reporting limit was approximate.

RA - Indicates the result was rejected, but is considered useable.

Table 2
Summary of Shallow Groundwater Conditions
Garfield Avenue Group of Sites
PPG, Jersey City, New Jersey

Phase	Amendment Dosage	Total Cr (µg/L)	Cr^{+6} (µg/L)	pH^{a} (s.u.)	ORP^{a} (mv)	DO^{a} (mg/L)	Reducing Conditions?	TAL Metals > GWQS?	Sulfide Present?
1A	2.8%	ND – 70	ND – 70	> 10	< -200	< 1	Y	Y	Y
1B	-	ND – 70	ND – 70	> 10	0 - (-200)	< 1	Y	Y	Y
	0.7%	70 – 1,000	ND – 70	6 – 8	< -100	< 1	Y	Y	Y
	2.0%	ND – 70	ND - 70	6 – 8	-100 - (-200)	< 1	Y	Y	Y
1C	2.8%	ND – 70	ND – 70	6 – 8	- 100 – 0	1 – 2	Y	Y	N
2A	-	ND – 70	ND – 70	6 - 11	0 - (-200)	1 - 2	Y	Y	N
2B-1	2.0%	70 - 1,000	ND – 70	6 – 8	- 100 – 0	< 1	Y	Y	N
2B-2	0.7%	ND – 70	ND – 70	6 – 8	-200 – (-100)	< 1	Y	Y	N
2B-3	0.7%	ND – 70	ND – 70	6 – 8	-200 – (-100)	< 1	Y	Y	N
2B-4	0.7%	ND – 70	ND – 70	6 – 8	- 100 – 0	1 – 2	Y	Y	N
	2.0%	ND – 70	ND – 70	6 – 8	- 100 – 0	< 1	Y	Y	N
3A	-	ND – 70	ND – 70	6 – 8	0 - 100	< 1	Y	Y	N
	0.7%	ND – 70	ND – 70	6 – 8	- 100 – 0	1 – 2	Y	Y	N
	2.0%	ND – 70	ND – 70	6 – 8	-100 - 0	1 - 2	Y	Y	N
3B	0.7%	ND – 70	ND – 72(J)	6 – 8	-100 – 0	1 – 2	Y	Y	N
	2.0%	70 – 1,000	ND – 70	6 – 8	-100 – 0	~ 1	Y	Y	Y
3C	0.7%	70 - 1,000	ND – 70	6 - 7	< -100	< 1	Y	Y	N
IRM #1	-	ND – 70	ND – 70	>10	0 - 100	< 1	Y	Y	N

Notes:

1. Data summarized in this table is based on samples collected between March and September 2016. This data has been previously presented in the *Progress Report for Groundwater Pilot Study and FerroBlack®-H Amended Backfill Permits-By-Rule – 2016 Fourth Quarter (October to December),* submitted in February 2017.
2. Amendment dosages are indicated on a weight percent basis.

^{a} - field measurements

Cr - chromium

Cr^{+6} - hexavalent chromium

DO - dissolved oxygen

GWQS - Groundwater Quality Standard

J - Indicates an estimated value

mg/L - milligrams per liter

mv - millivolts

ND - non-detect

ORP - oxidation-reduction potential

s.u. - standard units

TAL - target analyte list

µg/L - micrograms per liter

Y- Yes N- No

Table 3
Summary of Longevity Evaluation for FerroBlack®-H Amended Backfill Soils
Garfield Avenue Group of Sites
PPG, Jersey City, New Jersey

Phase and FB-H Dosage (% by wt.)	FB-H longevity (Years)[a]	Minimum thickness of amended fill required to sustain reductive capacity for 100 years (ft)	Minimum thickness of amended fill required to sustain reductive capacity for 30 years (ft)	Actual amendment thickness (ft)	FB-H applied (tons)
IRM #1 (0.7%)[b]	1,600	0.5	0.2	10.3	6
Phase 1A (2.8%)	16,000	0.4	0.13	19.0	776
Phase 1B (0.7%)	900	1.1	0.3	12.7	234
Phase 1C (2.8%)	12,000	0.1	0.04	14.5	1,234
Phase 2B-1 (2%)	200	6.7	2.0	12.3	1,365
Phase 2B-2 (0.7%)	400	5.2	1.6	10.9	149
Phase 2B-3 (0.7%)	700	3.4	1.0	13.2	148
Phase 2B-4 (0.7%)	700	2.4	0.7	13.4	326
Phase 3A (0.7%)	3,200	0.5	0.2	5.5	105
Phase 3B (0.7%)	3,200	0.5	0.2	17.0	180
Phase 3C (0.7%)	1,700	1.9	0.6	12.7	370

Phase and FB-H Dosage (% by wt.)	Average Downward Vertical Gradient	Presence of Cr^{+6} in Shallow Zone	Interaction of FB-H with Total Cr/Cr^{+6} from Intermediate Zone	Infiltration of Oxygen from Shallow Zone	Interaction of Oxygen from Intermediate Zone
IRM #1 (0.7%)[b]	Downward[c]	No	No	Yes	No
Phase 1A (2.8%)	Upward	No	Yes	Yes	Yes
Phase 1B (0.7%)	Upward	No	Yes	Yes	Yes
Phase 1C (2.8%)	Downward	No	No	Yes	No
Phase 2B-1 (2%)	Upward	No	Yes	Yes	Yes
Phase 2B-2 (0.7%)	Upward[c]	No	Yes	Yes	Yes
Phase 2B-3 (0.7%)	Upward	No	Yes	Yes	Yes
Phase 2B-4 (0.7%)	Upward	No	Yes	Yes	Yes
Phase 3A (0.7%)	Downward	No	No	Yes	No
Phase 3B (0.7%)	Downward	No	No	Yes	No
Phase 3C (0.7%)	Upward	No	Yes	Yes	Yes

Notes:

[a] - Rounded to nearest 100 years (for longevities of less than 10,000 years) and rounded to nearest 1,000 years (for longevities greater than 10,000 years).

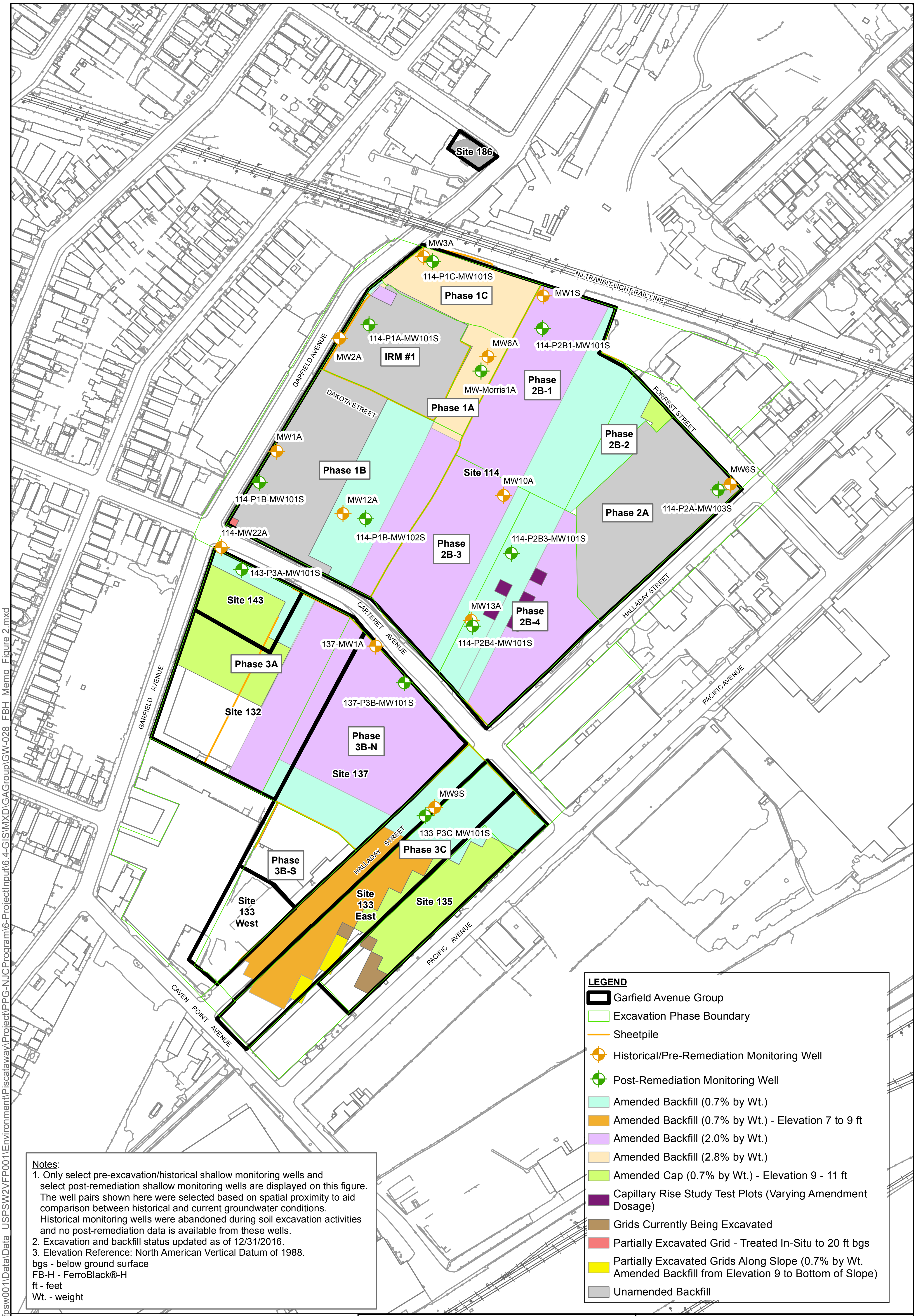
[b] - Only a portion of the IRM #1 area has been backfilled with FB-H amendment at 0.7% by wt.

[c] - Assumed, based on flow conditions in nearby phases.

1. The different phases at the Site with similar dosage of FB-H, ranging from 0.7% to 2.8% (by weight), have different FB-H longevities due to phase-specific variables such as chromium concentrations, areas, and treatment depths etc., leading to different oxygen fluxes and chromium fluxes per year in each phase.
2. Vertical hydraulic gradient data for IRM #1 and Phase 2B-2 are not available. In the longevity estimates, the groundwater gradient from nearby phases was used (i.e., from Phase 1C and Phase 2B-1 for IRM #1 and Phase 2B-2, respectively). Attachment C provides the input values used in the longevity estimates.
3. The FB-H Longevity value for Phase 3C will be revised upon the completion of the ongoing backfill amendment.
4. Horizontal hydraulic conductivity values were not available for each amended phase of the Site. Horizontal hydraulic conductivity values from neighboring phases with similar geology (i.e., presence/absence of meadow mat) were used to compute the vertical hydraulic conductivity and the vertical flow rates. Attachment D provides the input horizontal conductivity values used in the calculations.
5. Although FB-H is applied at different dosages in the excavation phases of the Site, the area with the lowest dosage within each phase was used in these calculations in order to estimate lowest amount of reductive capacity.
6. The Cr^{+6} concentrations used in these estimates were an average of the data collected from the last four sampling events in these areas.
7. The shallow zone dissolved oxygen (DO) concentrations used in these estimates were collected from Phase 2A (unamended area without meadow mat) in December 2016, to provide representative values. Total Cr and Cr^{+6} concentrations in this area are below the 70 micrograms per liter (µg/L) Groundwater Quality Standard (GWQS) and the DO would be consumed by the naturally available reductants in the soils. Additionally, due to the absence of meadow mat or an impermeable liner in this phase, the oxygen flux calculated using these values provides a representative snapshot of background DO conditions at the Site.

Cr - chromium
Cr^{+6} - hexavalent chromium
FB-H - FerroBlack®-H
ft - feet
wt. - weight

Figures



LEGEND

- ▭ Garfield Avenue Group
- ▭ Excavation Phase Boundary
- — Sheetpile
- ⊕ Historical/Pre-Remediation Monitoring Well
- ⊕ Post-Remediation Monitoring Well
- ▨ Amended Backfill (0.7% by Wt.)
- ▨ Amended Backfill (0.7% by Wt.) - Elevation 7 to 9 ft
- ▨ Amended Backfill (2.0% by Wt.)
- ▨ Amended Backfill (2.8% by Wt.)
- ▨ Amended Cap (0.7% by Wt.) - Elevation 9 - 11 ft
- ▨ Capillary Rise Study Test Plots (Varying Amendment Dosage)
- ▨ Grids Currently Being Excavated
- ▨ Partially Excavated Grid - Treated In-Situ to 20 ft bgs
- ▨ Partially Excavated Grids Along Slope (0.7% by Wt. Amended Backfill from Elevation 9 to Bottom of Slope)
- ▨ Unamended Backfill

Notes:

1. Only select pre-excavation/historical shallow monitoring wells and select post-remediation shallow monitoring wells are displayed on this figure. The well pairs shown here were selected based on spatial proximity to aid comparison between historical and current groundwater conditions. Historical monitoring wells were abandoned during soil excavation activities and no post-remediation data is available from these wells.
2. Excavation and backfill status updated as of 12/31/2016.
3. Elevation Reference: North American Vertical Datum of 1988.

bgs - below ground surface
FB-H - FerroBlack®-H
ft - feet
Wt. - weight

AECOM

0 100 200
Feet

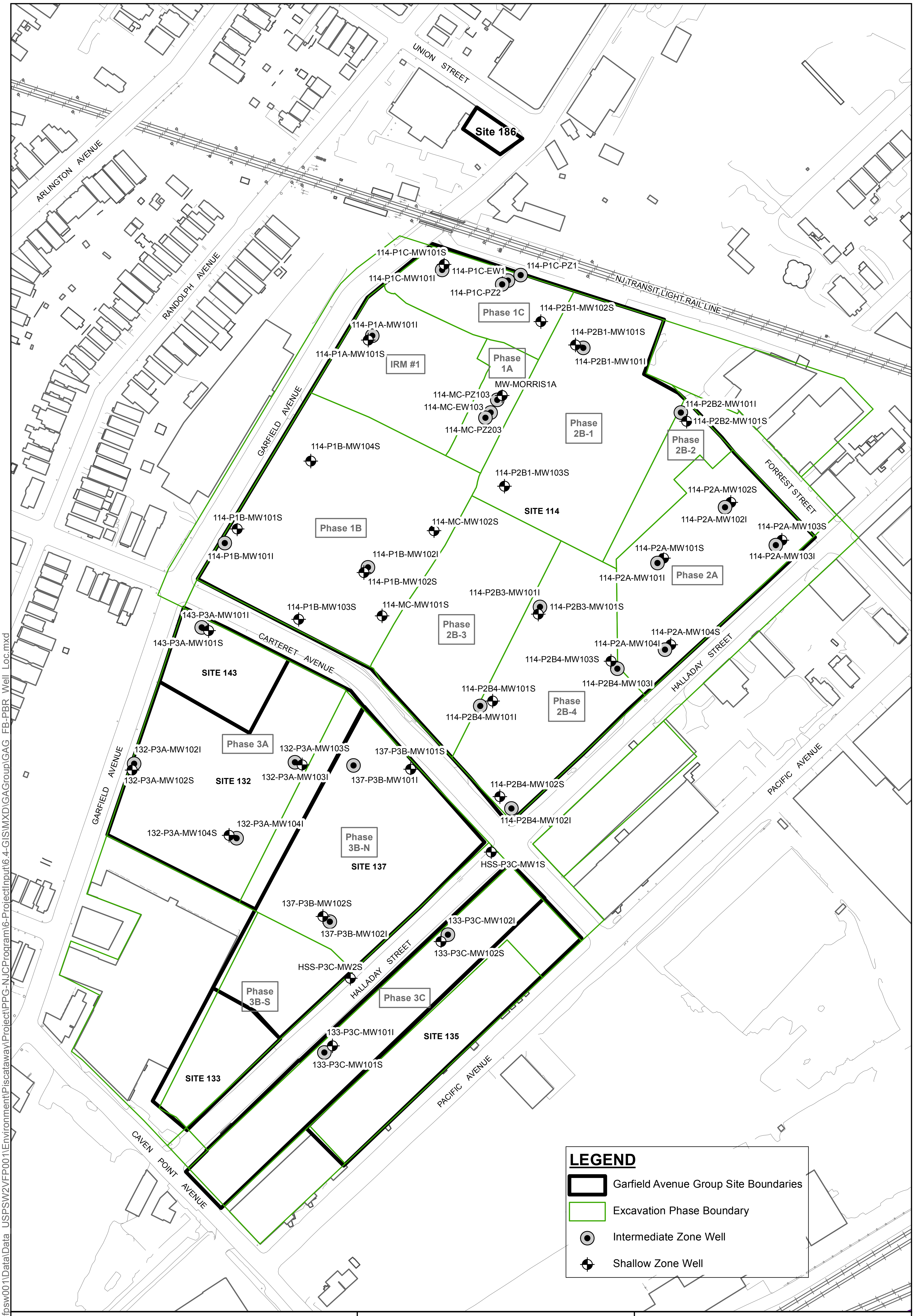
N
W E
S

PPG
GARFIELD AVENUE GROUP
JERSEY CITY, NEW JERSEY
60508053.GA.FB.PBR.RPT-OFFICE

DATE: 04/06/2017 | DRAWN BY: SR | CHECKED BY: SS

FIGURE 2
HISTORICAL (PRE-EXCAVATION) AND CURRENT MONITORING WELL LOCATIONS AND FB-H AREAS

Path: \\uspsw2pfpsw001\Data\Data USPSW2VFP001\Environment\Piscataway\Project\PPG-NJCProgram\6-ProjectInput\6.4-GIS\MXD\GAGroup\GW-028 FBH Memo Figure 2.mxd



Path: \\uspsw2pfpsw001\Data\Data_USPSW2\VFP001\Environment\Piscataway\Project\PPG-NJCProgram\6-ProjectInput\6.4-GIS\MXD\GAGroup\GAG_FB-PBR_Well_Loc.mxd

AECOM

0 150
Feet

N
W E
S

PPG
GARFIELD AVENUE PROJECT AREA, JERSEY CITY
HUDSON COUNTY, NEW JERSEY
60508053

DATE: 04/03/2017 | PM: Hellerich, Lucas | User: Ravi, Shree

FIGURE 3
MONITORING WELL NETWORK
FOR FERROBLACK-H PBR

ATTACHMENT A

GAG-029: Progress Update on FerroBlack-H Longevity Evaluation –
Garfield Avenue Group Chromium Sites, Jersey City, New Jersey
(July 30, 2015)

AECOM
30 Knightsbridge Road
Suite 520
Piscataway, NJ 08854

732 564 3600 tel
732 369 0121 fax

Memorandum

To	Brian McPeak (SA) Ben Delisle (JCRA) Peter Sorge (JM Sorge on behalf of Hampshire Group)	Page 1
CC	Mark Terril, PPG Brian McGuire, PPG Rich Feinberg, PPG Keith Prins, PPG Scott Mikaelian, PE, AECOM Aimee Ruiter, AECOM Cameron Dixon, AECOM Hue Quan, AECOM	
Subject	GAG-029: Progress Update on FerroBlack-H Longevity Evaluation Garfield Avenue Group Chromium Sites, Jersey City, New Jersey	
From	Lucas Hellerich, PhD, PE, LEP, AECOM Sachin Sharma, PE, AECOM Shree Ravi, EIT, AECOM	
Date	July 30, 2015	

1.0 Introduction and Purpose

At the request of PPG Industries, Inc., AECOM has prepared this progress update memorandum on the evaluation of FerroBlack-H longevity at the Garfield Avenue Group of Sites (the “Site”). On April 6, 2015, AECOM communicated that the following information was to be included in this memorandum (AECOM, 2015):

- FerroBlack-H longevity evaluation; and
- Application of FerroBlack-H at other non-Garfield Avenue sites.

Preliminary findings are summarized in this technical memorandum and additional evaluation is expected to be continued in the future as more analytical results and data from other project sites become available.

2.0 Overview of FerroBlack-H Application at the Site

Backfilling is currently underway at the Site, with FerroBlack-H amended fill already placed in several areas of Site 114, including Phases 1A, 1B, 1C, 2B-1, 2B-2, 2B-3 and 2B-4 in varying dosages. Groundwater monitoring wells have been installed in areas where excavation and backfilling have been completed, in order to monitor improvement in groundwater quality post soil remediation. These wells are sampled on a quarterly basis following their installation, for analytes including hexavalent chromium (“Cr^{+6}”), Target Analyte List (“TAL”) metals (including total chromium), pH, oxidation reduction potential (“ORP”), and sulfur species. The FerroBlack-H groundwater monitoring network is shown in **Figure 1**, along with dosages of the amendment across the Site (the locations where remedial work has not been completed show proposed amendment dosages). Additional wells are to be installed in the Phase 3 excavation areas once those excavations are completed and backfilled.

3.0 Evaluation of FerroBlack-H Longevity

3.1 Mechanism of Action

FerroBlack-H is a proprietary reagent of Redox Solutions, LLC. It is currently in use at the Site, amended to clean fill at dosages ranging from 0.7% to 2.8% by weight, as a measure to prevent recontamination of the clean fill by groundwater containing Cr^{+6}. As a subsequent benefit, the treated backfill is also providing preliminary remediation of groundwater. FerroBlack-H is a reductive mixture of soluble and insoluble sulfides. The soluble sulfides react rapidly with Cr^{+6}, reducing it to trivalent chromium (“Cr^{+3}”) which forms an immobile precipitate. The relatively insoluble ferrous sulfide (“FeS”) provides a longer term source of reductants (e.g. ferrous iron and sulfide) to treat Cr^{+6}.

The reduction of Cr^{+6} to Cr^{+3} is achieved by a combination of geochemical reactions. Both the iron and sulfide components of FerroBlack-H are involved in Cr^{+6} reduction. In addition to reducing Cr^{+6} to Cr^{+3}, the FerroBlack-H has the ability to precipitate the Cr^{+3} in the form of an iron-chromium complex, which, under pH conditions above 4, is relatively insoluble compared to chromium hydroxide precipitates. Research studies have hypothesized the formation of such a complex at pH values above 4 (M. Mullet, *et al*., 2004, Palmer *et al.,* 1994).

The occurrence of this co-precipitation phenomenon implies that there is a greatly reduced probability of Cr^{+3} getting re-oxidized to Cr^{+6} over time. In addition, the kinetics of re-oxidation of Cr^{+3} to Cr^{+6} are extremely slow (Palmer *et al*., 1994) and require an oxidizing agent such as manganese dioxide, peroxide, perchlorate, or ultraviolet rays. While peroxide, perchlorate, and ultraviolet rays are not naturally present in soils, manganese oxide minerals may be present and are the only minerals which can oxidize Cr^{+3} to Cr^{+6}. Manganese oxide minerals have been shown in laboratory studies to be capable of oxidizing Cr^{+3} to Cr^{+6}, however, this oxidation reaction is only one of many reduction-oxidation reactions that can occur in a soil or groundwater environment. For example, soil organic matter, ferrous iron, and sulfides can reduce Cr^{+6} to Cr^{+3}, overcoming oxidizing reactions. Reduction of chromium by ferrous iron (Fe(II)) is rapid and results in formation of a stable ferric iron (Fe(III)) Cr^{+3} hydroxide solid, thereby stabilizing chromium in an immobile state (Fendorf, 1995). Additionally, oxidation of Cr^{+3} by manganese dioxide minerals is limited by precipitation of reaction products, such as Cr(OH)3.nH2O, which inhibits further oxidation. Other precipitates such as, iron and aluminum hydrous oxides also precipitate on manganese oxides, inhibiting the oxidation of Cr^{+3} (Fendorf, 1995). Further evaluation of the presence of manganese dioxides at the Site is planned.

3.2 Site Groundwater Geochemistry and Chromium levels

Following the excavation of impacted soils and replacement with FerroBlack-H amended clean backfill, Cr^{+6} and Cr concentrations in shallow and intermediate groundwater backfill are reduced compared to historic (pre-remediation) levels. These chromium concentration reductions are related to the establishment of geochemically reducing conditions caused by the FerroBlack-H. Geochemical reducing conditions are characterized by low dissolved oxygen (less than 1 mg/L), negative ORP, and presence of reductants (i.e. ferrous iron and sulfide). A comparison of pre- and post-remediation conditions in shallow groundwater (in areas where FerroBlack-H has been applied) is presented in **Table 1**.

Hexavalent Chromium

Cr^{+6} data trends in shallow groundwater correlate well with the presence of the FerroBlack-H amended backfill and the ORP trends observed in this zone. Steady declines in Cr^{+6} concentrations were observed in wells where a sufficiently reducing environment had been established following the placement of FerroBlack-H amended backfill. Examples of these wells include 114-P1B-MW102S (0.7% dosage of FerroBlack-H) and 114-P2B1-MW103S (2.0% dosage of FerroBlack-H).These continued downward trends of Cr^{+6} are a favorable indication of the persistence of reducing conditions in the shallow zone, as well as of the longevity of the amendment. $Cr+^{6}$ trends for wells screened within and outside of the FerroBlack-H amended backfill are presented on **Figures 2A and 2B** in **Attachment 1**. Total chromium trends for wells screened within and outside of the FerroBlack-H amended backfill are presented on **Figures 2C and 2D**. There is an upward trend in late 2014 and early 2015, likely due to the inclusion of new wells in the monitoring program during this timeframe. It is anticipated that chromium concentrations will continue to decline over time.

Data collected from the March/April 2015 groundwater monitoring event indicate that the shallow zone concentration of Cr^{+6} in areas where the amendment has been applied is under the GWQS of 70 ug/L in all of the wells, with a few minor exceedances reported for total chromium alone. The chromium data (for unfiltered samples) in the shallow zone from the March/April 2015 monitoring event is summarized below in **Table A** presented below. Compared to pre-remediation conditions, there has been a significant improvement in groundwater quality with respect to Cr^{+6} upon the application of FerroBlack-H. In phases that have received the amendment, reductions of 90% – 100% from pre-remediation levels have been reported.

Table A. Summary of Shallow Zone Chromium Data from the March/April 2015 Monitoring Event

Excavation Phase	Well ID	Screened Interval	Amendment Type	Total Cr	Cr^{+6}
		ft. bgs		ug/L	ug/L
IRM #1	114-P1A MW101S	5 - 15	Unamended Clean Backfill	3,750	2,800
1A	MW-Morris 1A	10 – 20	Amended Backfill (2.8% by wt.)	< 0.60	< 3.1
1B	114-P1B-MW101S	4 - 14	Unamended Clean Backfill	< 0.60	< 3.1
	114-P1B-MW102S	5 – 15	Amended Backfill (0.7% by wt.)	137	< 3.1
	114-P1B-MW103S	6.5 - 16.5	Unamended Clean Backfill	2.1	< 3.1
	114-P1B-MW104S	4.2 - 14.2	Unamended Clean Backfill	83.7	73
1C	114-P1C-MW101S	2 – 12	Amended Backfill (2.8% by wt.)	8 J	23

Excavation Phase	Well ID	Screened Interval	Amendment Type	Total Cr	Cr^{+6}
		ft. bgs		ug/L	ug/L
2B-1	114-P2B1-MW101S	3 – 13	Amended Backfill (2.0% by wt.)	< 6	< 3.1
	114-P2B1-MW102S	9 – 19	Amended Backfill (2.8% by wt.)	201	22
	114-P2B1-MW103S	3 – 13	Amended Backfill (2.0% by wt.)	12.4	39
2B-2	114-P2B2-MW101S	4.5 – 14.5	Amended Backfill (0.7% by wt.)	666	< 3.1
2B-3	114-P2B3-MW101S	6 – 16	Amended Backfill (0.7% by wt.)	47.1	< 3.1
2B-4	114-P2B4-MW101S	8 – 18	Amended Backfill (0.7% by wt.)	384	39
	114-P2B4-MW102S	8 – 18	Amended Backfill (2.0% by wt.)	< 3.0	< 3.1
	114-P2B4-MW103S	6 – 16	Amended Backfill (2.0% by wt.)	58.7	< 3.1

Notes:

🟩	= wells screened within FerroBlack-H amended backfill
Bold	= Indicates exceedance of GWQS for total chromium (70 ug/l)
ug/L	= micrograms per liter or parts per billion (“ppb”)
ft. bgs	= feet below ground surface

pH

The pH in the shallow zone groundwater ranged from approximately 6 to 11 standard units ("s.u.") in FerroBlack-H amended areas of the Site, based on data collected in the field during the round of sampling conducted between March and April of 2015. In the areas where amended backfill has been placed, an overall downward trend has been observed in pH. Trends of pH collected in the field during sampling are presented on Figures **2E and 2F** in **Attachment 1**. In areas where amended backfill has been placed, the average pH for the groundwater at the Site has moderated from alkaline conditions to approximately 7 and 8 s.u. (neutral conditions). In areas outside of where amended backfill has been placed, the average pH of the groundwater ranges between 10 and 12 s.u.

ORP

The ORP in the shallow zone groundwater at the Site where the FerroBlack-H amendment was placed was found to be negative (ranging from -70 millivolts ("mv") to -471 mv), based on data collected in the field during the round of sampling conducted between March and April of 2015. Optimal reducing conditions for FerroBlack-H activity includes an ORP of less than -200 mv (Brown *et. al*., 2008); however, reduction will occur under conditions when ORP values are less negative. In the intermediate zone groundwater, ORP was found to be in the reducing range (i.e., less than 0 mv) in areas below where amended fill with higher dosages of FerroBlack-H was applied (e.g., Phase 1C and the former Morris Canal area). In other areas where no amendment has been put in place, or lower concentrations of the amendment have been applied (0.7% by weight), the ORP was found to be positive. However, since FerroBlack-H is not applied at intermediate depths, these observations of positive ORP values are expected.

Trends of ORP collected in the field during sampling for the shallow zone are presented on **Figures 2G and 2H** in **Attachment 1**. Average ORP vales have reduced significantly in both the shallow and intermediate zones. The ORP has risen from minimum levels due to the consumption of the soluble sulfides. It is anticipated that the FeS which is still present will continue to result in a negative ORP over time. Overall, the ranges of ORP over time indicate that reducing conditions are persistent in both the shallow and intermediate zones.

Dissolved Oxygen:

Measurements taken in the field during groundwater sampling conducted in November and December 2014 indicated that both the shallow and intermediate zones have dissolved oxygen ("D.O.") less than 3 mg/L. Out of 11 samples analyzed in the shallow zone, three samples reported dissolved D.O. concentrations at less than 1 mg/L, which is indicative of a reducing environment. These three samples were collected from areas where FerroBlack-H has been applied to the backfill material. Five samples reported concentrations ranging from 1 to 3 mg/L, while the remaining three samples reported D.O. levels greater than 3 mg/L. Similarly, in the intermediate zone, out of ten groundwater samples analyzed, two samples reported D.O. levels less than 1 mg/L, four samples had D.O. concentrations ranging from 1 to 3 mg/L, while the remaining four samples reported D.O. levels greater than 3 mg/L. Ideal reducing conditions in the subsurface would represent a D.O. concentration of close to zero. Certain D.O. measurements collected in the field were anomalous, and were not considered in this evaluation. Overall, the oxygen levels present at the Site are low compared to initial chromium concentrations and are not anticipated to significantly deplete the FeS through oxidation processes, and therefore will not interfere with the reduction of chromium.

Total and Dissolved Sulfides

Sulfide in amended soils and in groundwater is expected to be present since it is a component of FerroBlack-H. Sulfide is also another useful indicator of a reductive geochemical environment. During the March and April 2015 monitoring event, sample results indicated that total sulfides are present in groundwater at concentrations greater than 1 part per million ("ppm") in four of the eleven shallow zone groundwater samples collected from amended depths. Only one well (MW-Morris1A) had sulfide levels greater than 100 ppm; this is due to the higher dose of FerroBlack applied in this area of the Site. It is anticipated that the sulfide levels will decline over time as they react with hexavalent chromium and other oxidizing agents such as oxygen.

The data on total sulfur species in the shallow zone groundwater is presented in **Figure 2I** in **Attachment 1**. The concentration of sulfate in the shallow zone was not found to decrease or increase significantly compared to pre-remediation levels. Sulfide and sulfate data will continue to be collected as part of the FerroBlack-H Permit-By-Rule ("PBR") monitoring program.

3.3 Effect of other Target Analyte List metals on FerroBlack-H longevity

The longevity of insoluble sulfides in backfilled soils also depends on the concentration of other reactive metals and the presence of oxygen. FerroBlack-H reacts with several other metals other than chromium under feasible redox conditions (e.g. mercury, arsenic, lead, cadmium) and significant concentrations of these other metals may deplete the FeS available for long term treatment of Cr^{+6}. Evaluation of shallow and intermediate zone groundwater quality indicates that certain TAL metals are present in concentrations above their respective Groundwater Quality Standards ("GWQS") at several locations, most notably at MW-Morris 1A (FerroBlack-H dosage: 2.8% by wt.) in the shallow zone, and in 114-P1A-MW101I (unamended) and 114-P1B-MW102I (screened below 0.7% amendment) in the intermediate zone.

Following amended backfill placement, several TAL metals declined in concentrations in the shallow wells screened within FerroBlack-H amended depths. Metals that experienced reductions in concentrations primarily include antimony, arsenic, cadmium, lead, and selenium. The concentrations of mercury continued to remain below the GWQS. Although the concentrations of calcium, manganese, and sodium in the shallow zone are above their respective GWQS, these metals are not expected to interact with FerroBlack-H and are hence not expected to negatively impact the longevity of the amendment. Iron is a component of FerroBlack-H and is a metal mobilized due to the reducing conditions caused by FerroBlack-H. Further, the concentrations of the other TAL metals are also relatively low compared to the concentrations of Cr^{+6}; therefore, it is anticipated that the reaction of FeS with these TAL metals will be negligible.

3.4 Laboratory studies on FerroBlack-H

Column testing studies performed by SECOR International, Inc. evaluated the Cr^{+6}, pH and ORP levels of soil amended with FerroBlack-H over a period of 50 days, simulating the equivalent of 30-50 years of groundwater flow (Brown *et. al*., 2008). The results from this testing indicated that the treated soil had ORP values well within the reducing range (less than -200 mv) over the period of testing. The testing demonstrated persistence of reducing conditions of the soils treated with FerroBlack-H and indicated that the FerroBlack-H would continue to reduce residual Cr^{+6} over long timeframes. This study suggests that depletion of the amendment over a short period is not of a concern; however monitoring will be continued to further support that FerroBlack-H will be able to reduce Cr^{+6} over the long-term .

4.0 Application of FerroBlack-H at Other Sites

Upon discussions with the vendor of FerroBlack-H, AECOM has learned that FerroBlack-H is currently in use or has been successfully applied at five project sites across the country (AECOM, 2015). These sites are listed below:

Site	Location	Contaminant(s) of Concern	Matrix
H&L Plating (Former plating site)	Muncie, IN	Cr^{+6}, copper (Cu), arsenic (As), nickel (Ni)	Soil & groundwater
Global manufacturing and industrial equipment supplier (Confidential)	York, SC	Cr^{+6}	Soil & groundwater
Heritage Environmental Services (Part B Hazardous waste Treatment Facility)	Indianapolis, IN	mercury (Hg) & Cr^{+6}	Solid waste
CCA Processing Plant (Wood Preserving Facility)	Federalsburg, MD	Cr^{+6}, Cu & As	Soil & groundwater
Former Manufacturing Plant	Grapevine, TX	Cr^{+6}	Groundwater

The confidential nature of these remediation projects limits the amount of information publicly available, including the locations of these sites. Information on one of these project sites located in Muncie, IN is publicly accessible, and key observations from this project are summarized below:

- FerroBlack-H was applied through injection into the subsurface rather than blending with backfill prior to placement.
- FerroBlack-H was successful in reducing Cr^{+6} contamination in both soil and groundwater from pre-remediation concentrations ranges of 800,000 ppb – 9,700,000 ppb (groundwater) and 3,600 mg/kg (soil) to achieve the cleanup goals of 100 ppb for groundwater. The concentration of Cr^{+6} in soil was reduced to less than 5 mg/kg in all of the post-treatment samples analyzed.
- Significant reductions in aqueous Cr^{+6} were observed after the first quarter following groundwater injections.
- Other metals detected at elevated concentrations (arsenic, nickel, antimony) were also remediated using FerroBlack-H injections into groundwater and in-situ soil blending.

For the project sites located in South Carolina and Maryland, AECOM has submitted Freedom of Information Act (FOIA) requests to their respective state regulatory agencies on May 11, 2015 to access project reports that detail the use of FerroBlack-H. On June 4, 2015, the Maryland Department of the Environment ("MDE") responded to AECOM's request stating that no records exist for the information requested. Response from the South Carolina Department of Health and Environmental Control ("DHEC") is still pending. Upon receipt of the requested project documents, AECOM will summarize the available information on the use of FerroBlack-H at these sites along with conclusions in a separate technical memorandum. FOIA requests with local authorities of the respective sites will also be filed in the future. The site addresses for the remainder of the sites (located in Indiana and Texas) are currently unavailable, and AECOM is working on obtaining this information, after which file access requests will be prepared and submitted to the concerned state agencies if the addresses can be obtained.

5.0 Conclusions

Based on the above preliminary findings, the following can be concluded:

- Available literature demonstrates that FerroBlack-H is capable of creating and maintaining reducing conditions (ORP values less than -200 mv) in the subsurface for an extended period of time (approximately 50 years). It is expected that FerroBlack-H will be capable of treating hexavalent chromium at the Site for a similar amount of time. These results and expectations will be confirmed for the Site by collecting field based data and conducting additional calculations.
- Cr^{+6} reduction has been achieved at other sites through the application of FerroBlack-H coupled with a reducing geochemical environment, including very low levels of D.O. and negative ORP. Successful remediation of other heavy metals such as antimony and nickel has also been achieved with this technology, both in soil and groundwater.
- At the Garfield Avenue Site, evaluation of groundwater data indicates that negative ORP conditions exist, and are expected to be sustained. The optimal reducing conditions for FerroBlack-H activity include an ORP of less than -200 mv (Brown *et. al*., 2008). Following placement of the amended backfill, ORP is negative (ranging between -400 mv to -100 mv) and concentrations of Cr^{+6} and total chromium, as well as a number of TAL metals are reducing continuously.

6.0 Future Action

The following future action is proposed to demonstrate the Site specific longevity of the FerroBlack-H:

- FerroBlack-H activity and longevity is a function of Site-specific geochemical conditions and, in order to more subjectively evaluate the longevity of the reagent with respect to the Site, additional groundwater and soil data will be collected over time to ensure that reducing conditions persist, and to estimate the rate of reductant depletion from amended soils. Specifically, analytes of interest would include heavy metals (including chromium), sulfur species (total sulfur, sulfate, sulfite, sulfide), pH, ORP, ferrous iron (“Fe^{+2}”), ferric iron (“Fe^{+3}”), D.O., ORP, pH, and manganese oxides (in soil).

7.0 References

AECOM, 2015. GAG 004F- FerroBlack–H Studies Status memo.

Brown, Richard, Carlblom, Leland, Jacobs, Rick, Post, Gordon. 2008. *In-situ Chemical Reduction of Hexavalent Chrome at Chromite Ore Processing Residue Sites.* May 2008.

Fendorf, S.E. 1995. *Surface Reactions of Chromium in Soils and waters* in Geoderma, vol 67, p. 55-71.

Mullet, Martine, Boursiquot, Sophie, Ehrhardt, Jean-Jacques. 2004. *Removal of hexavalent chromium from solutions by mackinawite, tetragonal FeS*. August 2004.

Palmer, C. D. and R. W. Puls, 1994. Natural Attenuation of Hexavalent Chromium in Groundwater and Soils, EPA Groundwater Issue. October 1994."Pyrolusite from New Jersey, USA." Pyrolusite from New Jersey, USA. N.p., n.d. Web. 21 July 2015. <http://www.mindat.org/minloclist.php?m=3318&l=14024>.

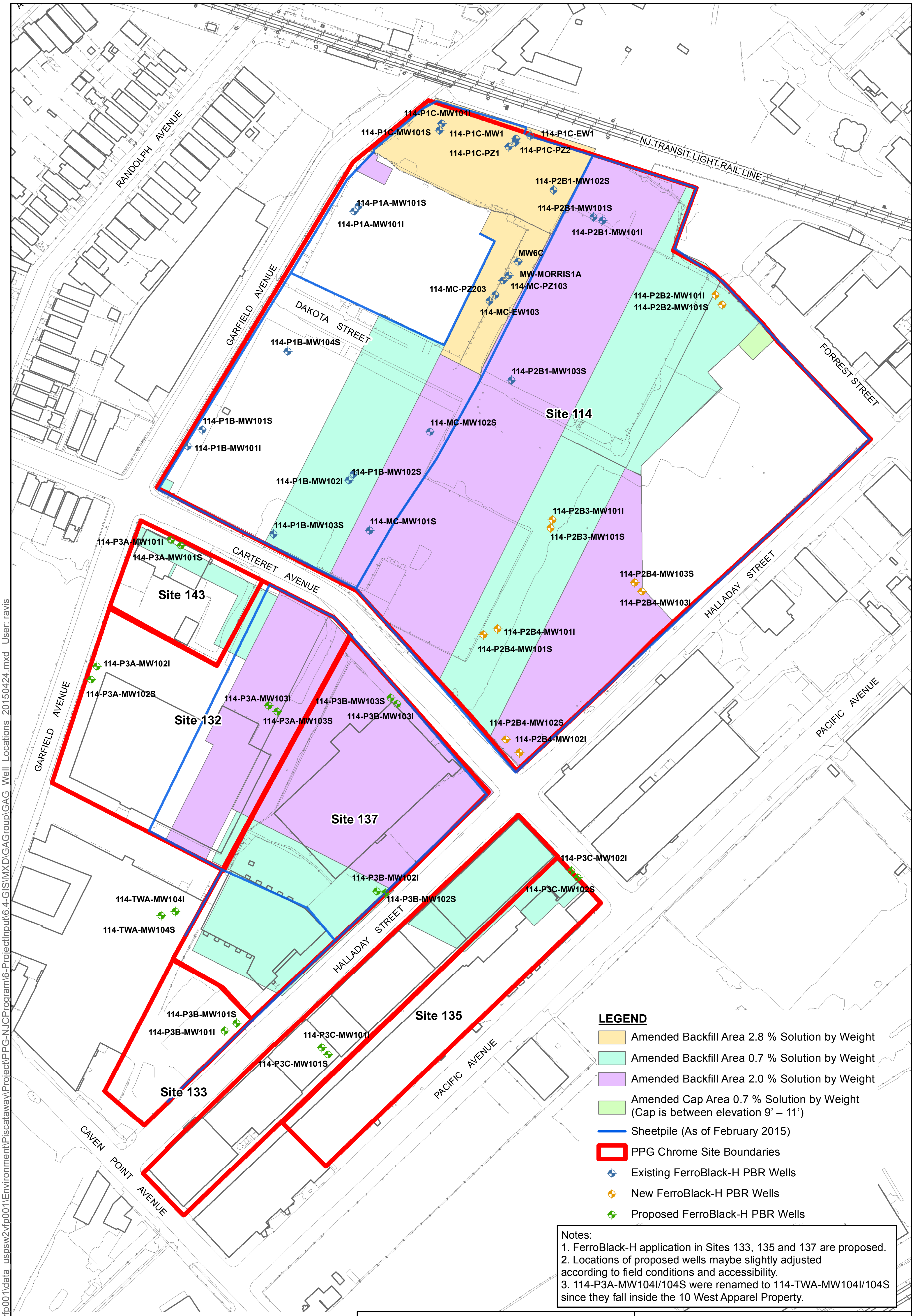
TABLE 1

Table 1
Pre- and Post-Remediation Conditions in Shallow Zone Groundwater
GA Group of Sites - PPG Industries, Inc.
Jersey City, New Jersey

Analyte	Units	Phase 1A		Phase 1B		Phase 1C		Phase 2B-1		Phase 2B-3		Phase 2B-4	
		Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
CHROMIUM (HEXAVALENT)	ug/l	534000	6.1	16200	110	< 1.5	23	17100	< 3.1	52900	< 3.1	151000	39
PH	s.u.	11.98	11.26	9.36	7.22	6.5	7.09	11.99	6.49	11.73	7.18	6.96	6.75
OXIDATION-REDUCTION POTENTIAL (ORP)	mv	NA	-474.9	NA	-110	-99.9	-114	11.6	47	NA	-131	12.9	-111
TAL Metals													
ALUMINUM	ug/l	2550	1510	7440	1850	< 200	582	2550	221	7530	1180	2270	963
ANTIMONY	ug/l	192	< 52	< 5.0	< 6.5	< 5	< 3.0	< 29.0	< 3.0	13.3	< 3.0	< 1.8	< 30
ARSENIC	ug/l	< 50	< 51	99.8	12.8	44.0	< 3.6	< 2.8	< 12	9.2	< 6.0	68.6	28.7
BARIUM	ug/l	< 200	454	< 200	173	< 200	47.9	2.0	16.4	< 200	32.1	< 200	83.7
BERYLLIUM	ug/l	< 50	< 0.80	< 1.0	< 1.0	< 5	< 0.35	< 0.30	< 0.35	< 5	< 0.35	< 1.0	0.70
CADMIUM	ug/l	< 4	< 1.4	< 4.0	< 1.8	< 4	< 0.25	< 0.40	0.70	< 4	< 0.25	< 4.0	< 2.5
CALCIUM	ug/l	109000	682000	10400	70700	165000	140000	92000	455000	83100	555000	223000	1080000
CHROMIUM	ug/l	402000	6.0	18600	465	236	8.0	18600	< 6.0	55100	47.1	127000	384
COBALT	ug/l	< 50	5.0	< 50	7.5	< 50	1.3	< 1.7	78.8	< 50	< 1.5	< 50	< 3.0
COPPER	ug/l	58.4	295	50.4	26.5	82.3	1.9	< 3.7	< 1.9	< 25	5.2	< 25	30.1
IRON	ug/l	< 1000	23800	3130	20400	8720	9510	< 39.2	3370	1200	57000	100	257000
LEAD	ug/l	51.0	< 26	187	77.8	18.8	< 5.1	< 2.7	< 17	7.0	< 8.5	4.8	< 17
MAGNESIUM	ug/l	< 5000	< 83	7870	48800	10900	19700	< 41.6	119000	< 5000	76700	< 5000	383000
MANGANESE	ug/l	< 15	< 0.96	64.6	432	97.4	2510	< 1.2	30600	21.9	21900	< 15	107000
MERCURY	ug/l	< 0.4	< 0.38	0.46	1.6	< 0.4	< 0.069	< 0.10	< 0.069	< 0.2	< 0.069	< 0.2	< 0.069
NICKEL	ug/l	520	30.6	60.9	130	< 40	9.3	< 2.4	210	147	< 3.1	566	16.1
POTASSIUM	ug/l	181000	224000	103000	82600	40300	19600	12000	42600	36000	45600	54500	139000
SELENIUM	ug/l	< 50	< 73	28.1	< 9.1	< 5	< 2.2	< 4.2	< 22	< 25	21.6	7.1	29.9
SILVER	ug/l	< 10	12.4	< 10	5.0	< 10	2.0	< 1.4	11.1	< 10	4.5	< 10	10.5
SODIUM	ug/l	841000	9970000	2190000	1810000	808000	795000	144000	1120000	543000	1370000	1100000	5040000
THALLIUM	ug/l	< 100	< 37	< 10	< 4.6	< 10	< 4.7	< 1.9	< 16	< 10	< 16	< 0.75	< 31
VANADIUM	ug/l	< 500	35.2	691	69.5	66.5	3.2	175	18.8	124	1.1	19.7	12.8
ZINC	ug/l	< 200	90.6	184	153	167	< 4.9	11.8	362	< 20	< 24	< 20	< 49

Notes:
Pre-remediation data is from 2005-2011.
Post-remediation data is from 2015.
All results are for unfiltered samples only.
ug/l - micrograms per liter
s.u. - standard units
mv - millivolts
NA - Not Available

FIGURE 1



LEGEND

🟨 Amended Backfill Area 2.8 % Solution by Weight

🟩 Amended Backfill Area 0.7 % Solution by Weight

🟪 Amended Backfill Area 2.0 % Solution by Weight

🟩 Amended Cap Area 0.7 % Solution by Weight
(Cap is between elevation 9' – 11')

━ Sheetpile (As of February 2015)

▭ PPG Chrome Site Boundaries

⊕ Existing FerroBlack-H PBR Wells

⊕ New FerroBlack-H PBR Wells

⊕ Proposed FerroBlack-H PBR Wells

Notes:
1. FerroBlack-H application in Sites 133, 135 and 137 are proposed.
2. Locations of proposed wells maybe slightly adjusted according to field conditions and accessibility.
3. 114-P3A-MW104I/104S were renamed to 114-TWA-MW104I/104S since they fall inside the 10 West Apparel Property.

Path: \\Uspsw2vfp001data_uspsw2vfp001\Environment\Piscataway\Project\PPG-NJC\Program\6-ProjectInput\6.4-GIS\MXD\GAGroup\GAG_Well_Locations_20150424.mxd User: ravis

AECOM

0 150
Feet

N
E
S
W

PPG INDUSTRIES
GARFIELD AVENUE PROJECT AREA, JERSEY CITY
HUDSON COUNTY, NEW JERSEY
60317455.GA.FB.PBR.RPT.office

DATE: 06/18/2015 PM: Lucas Hellerich

FIGURE 1
FERROBLACK-H MONITORING WELLS

ATTACHMENT 1

Figure 2A
Hexavalent Chromium– Shallow Zone Groundwater
[Wells screened within FerroBlack-H amended backfill]
GA Group of Sites – PPG Industries, Inc.
Jersey City, New Jersey

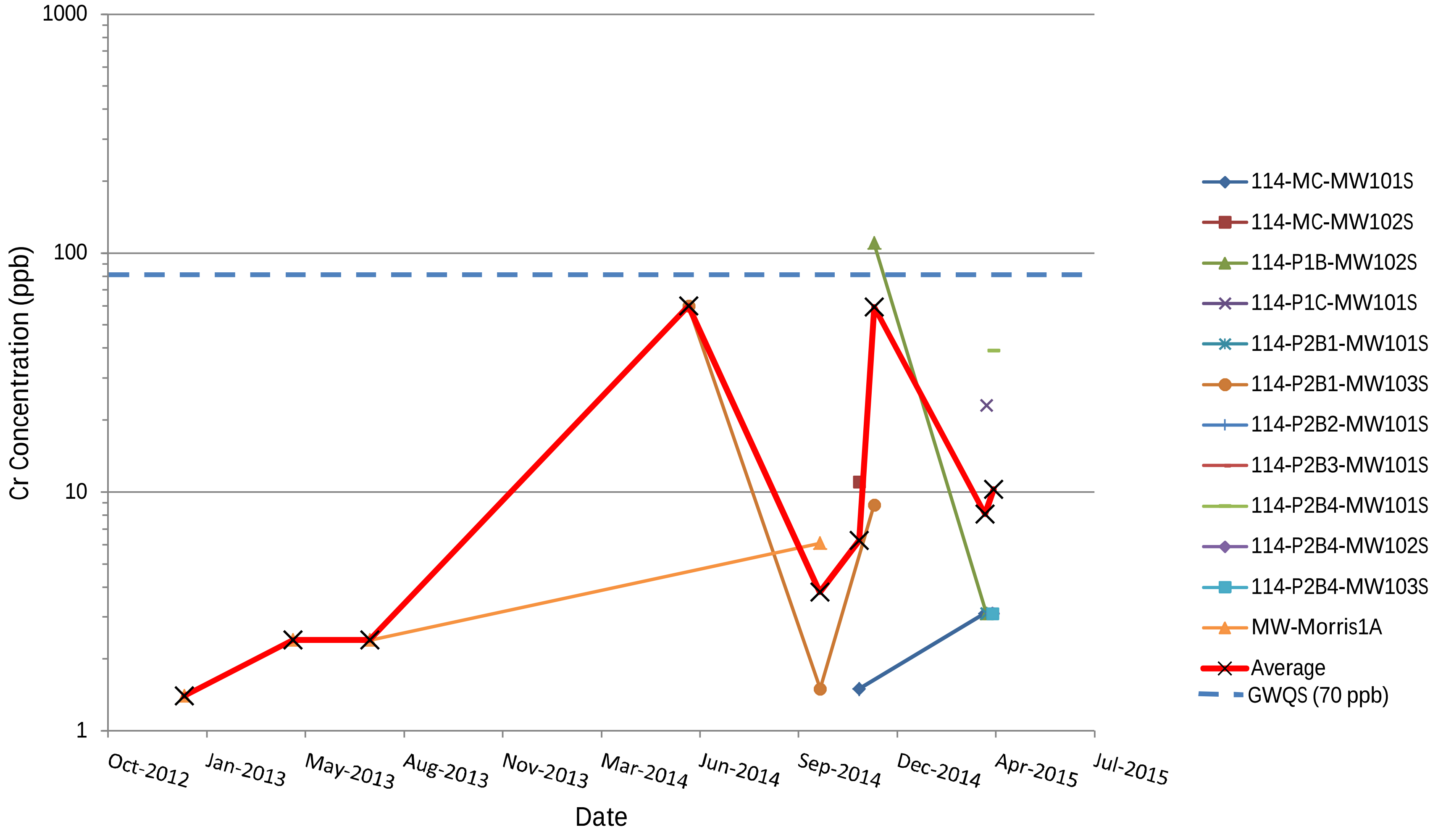


Figure 2B
Hexavalent Chromium– Shallow Zone Groundwater
[Wells screened outside FerroBlack-H amended backfill]
GA Group of Sites – PPG Industries, Inc.
Jersey City, New Jersey

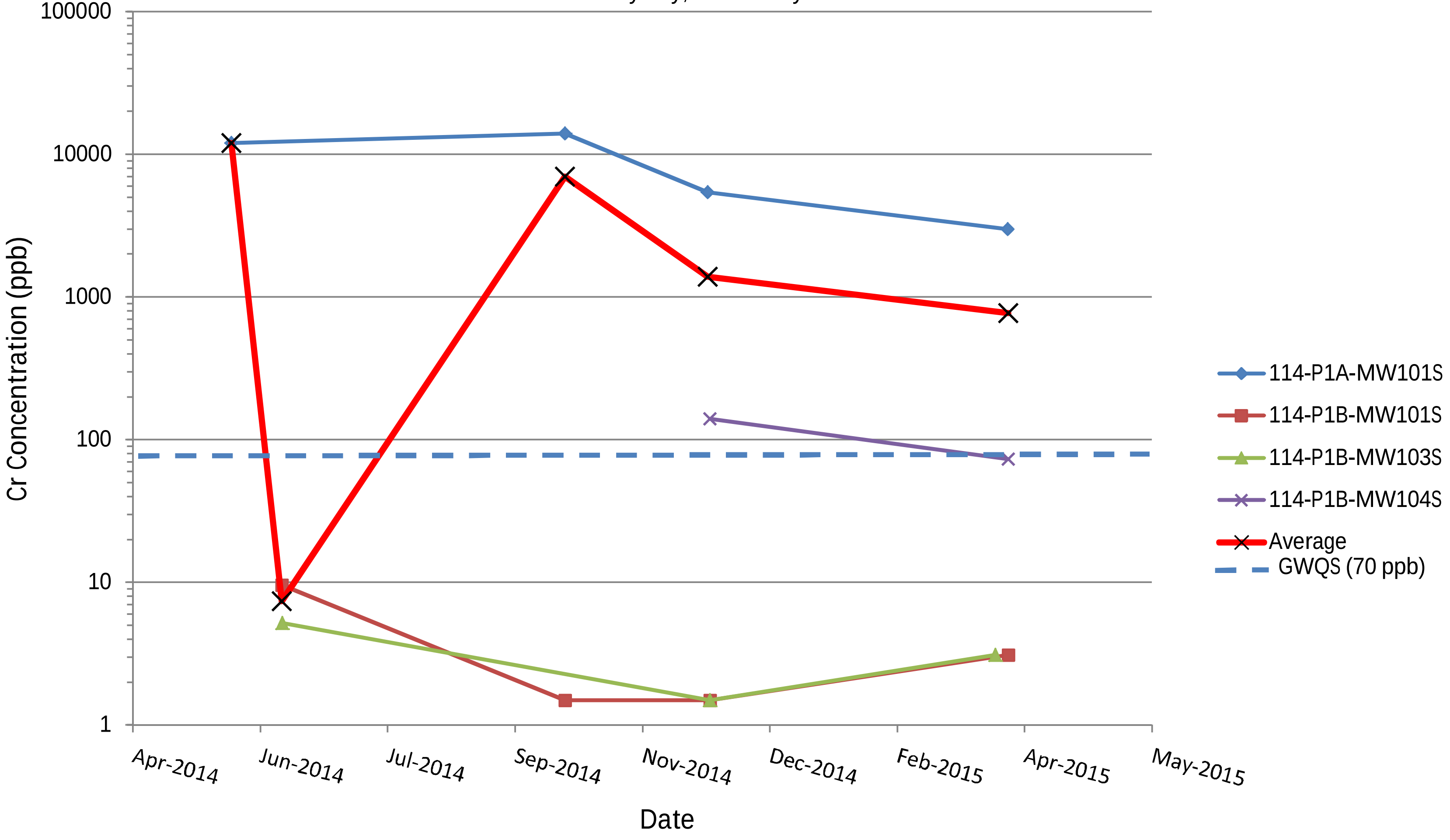


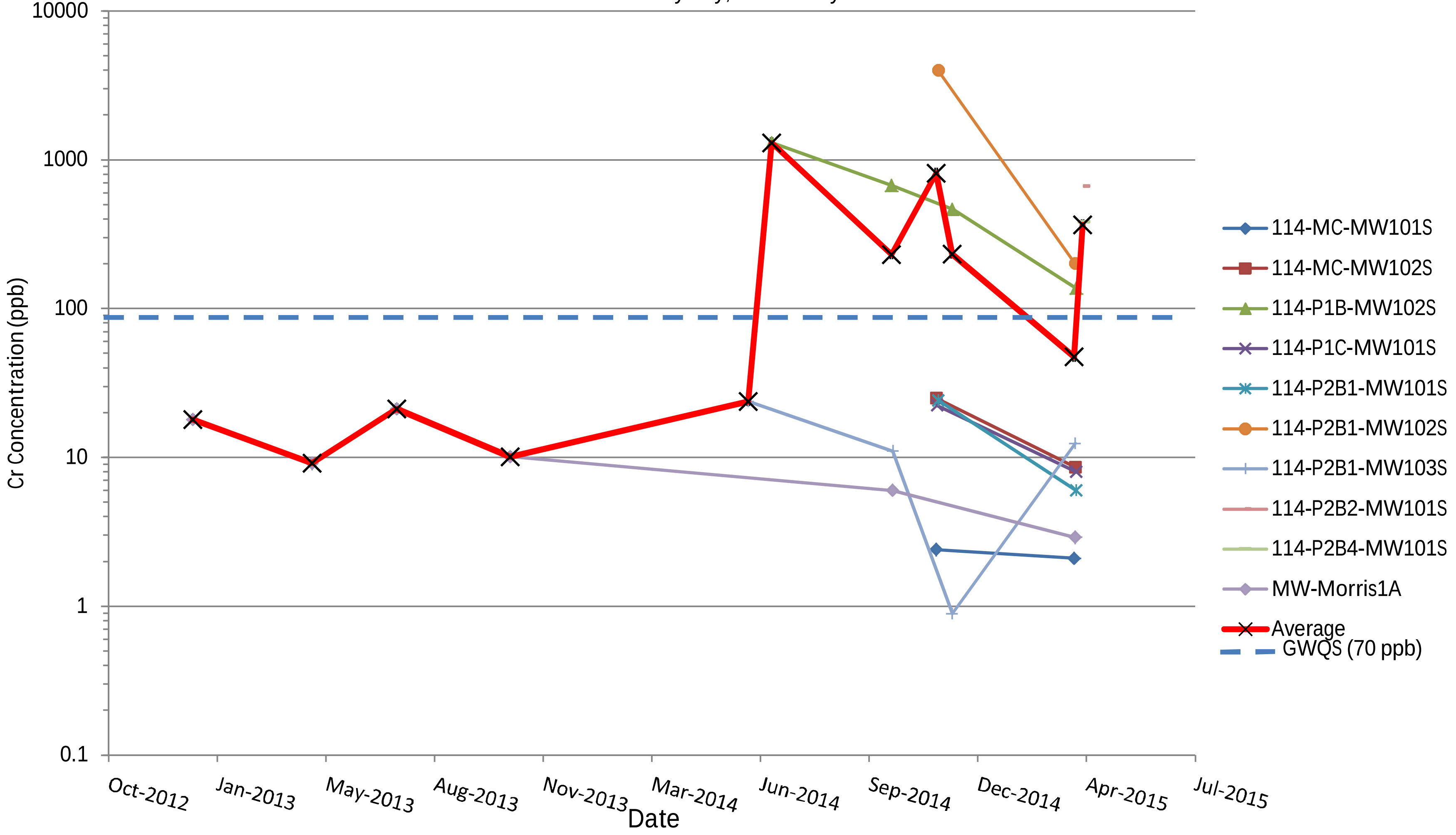
Figure 2C

Total Chromium– Shallow Zone Groundwater

[Wells screened within FerroBlack-H amended backfill]

GA Group of Sites – PPG Industries, Inc.

Jersey City, New Jersey



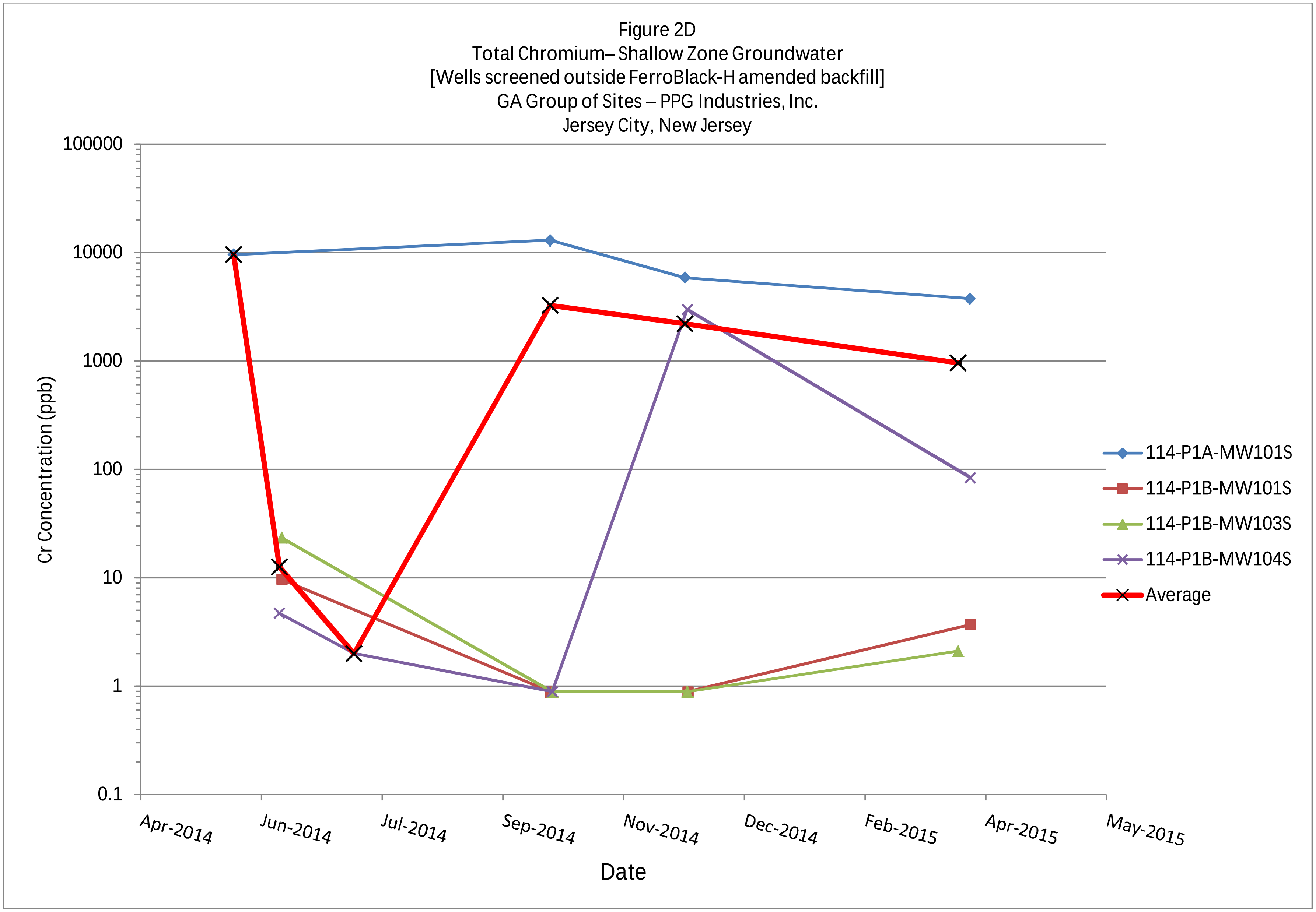


Figure 2D
Total Chromium– Shallow Zone Groundwater
[Wells screened outside FerroBlack-H amended backfill]
GA Group of Sites – PPG Industries, Inc.
Jersey City, New Jersey

Figure 2E
pH– Shallow Zone Groundwater
[Wells screened within FerroBlack-H amended backfill]
GA Group of Sites – PPG Industries, Inc.
Jersey City, New Jersey

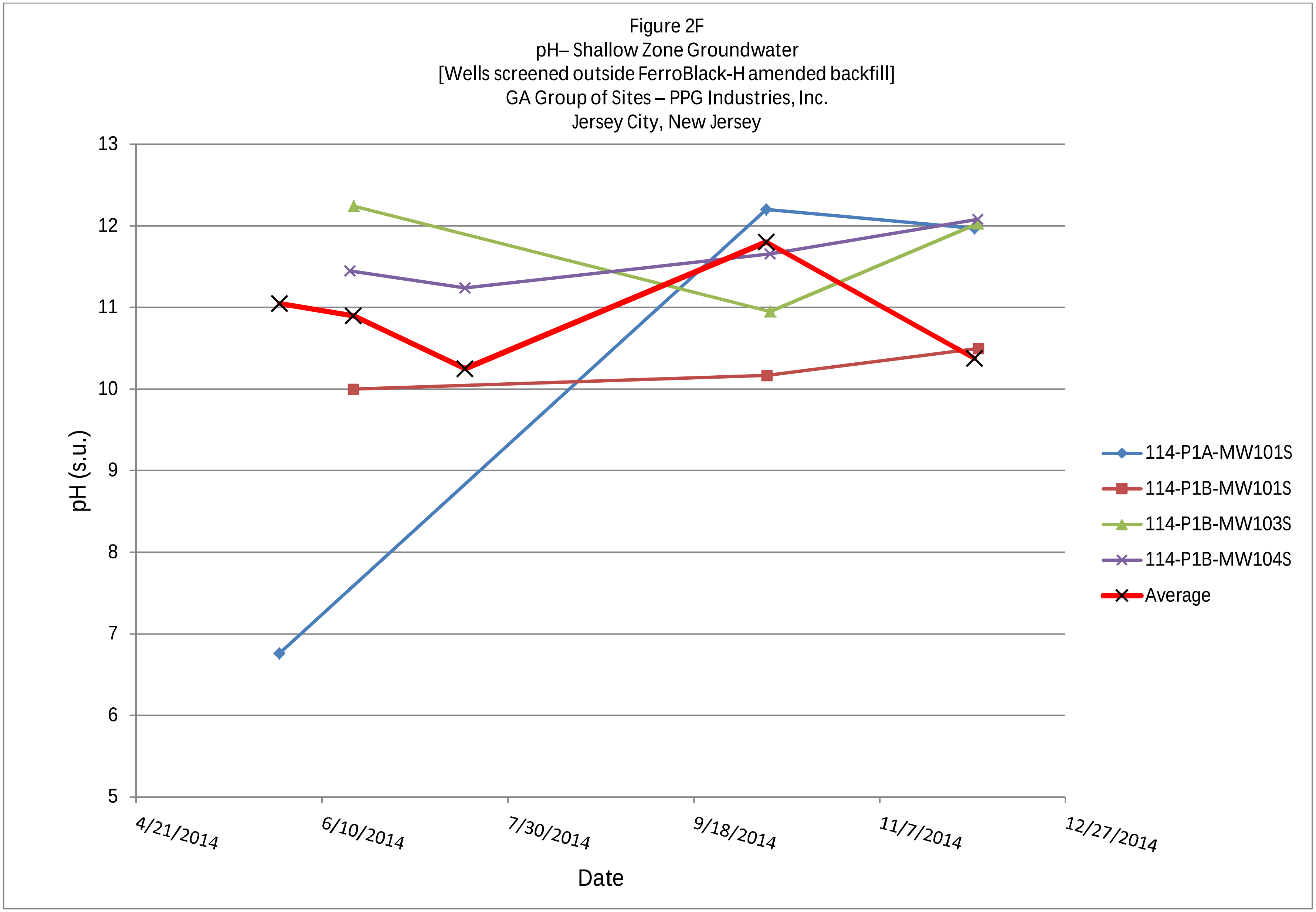


Figure 2F
pH– Shallow Zone Groundwater
[Wells screened outside FerroBlack-H amended backfill]
GA Group of Sites – PPG Industries, Inc.
Jersey City, New Jersey

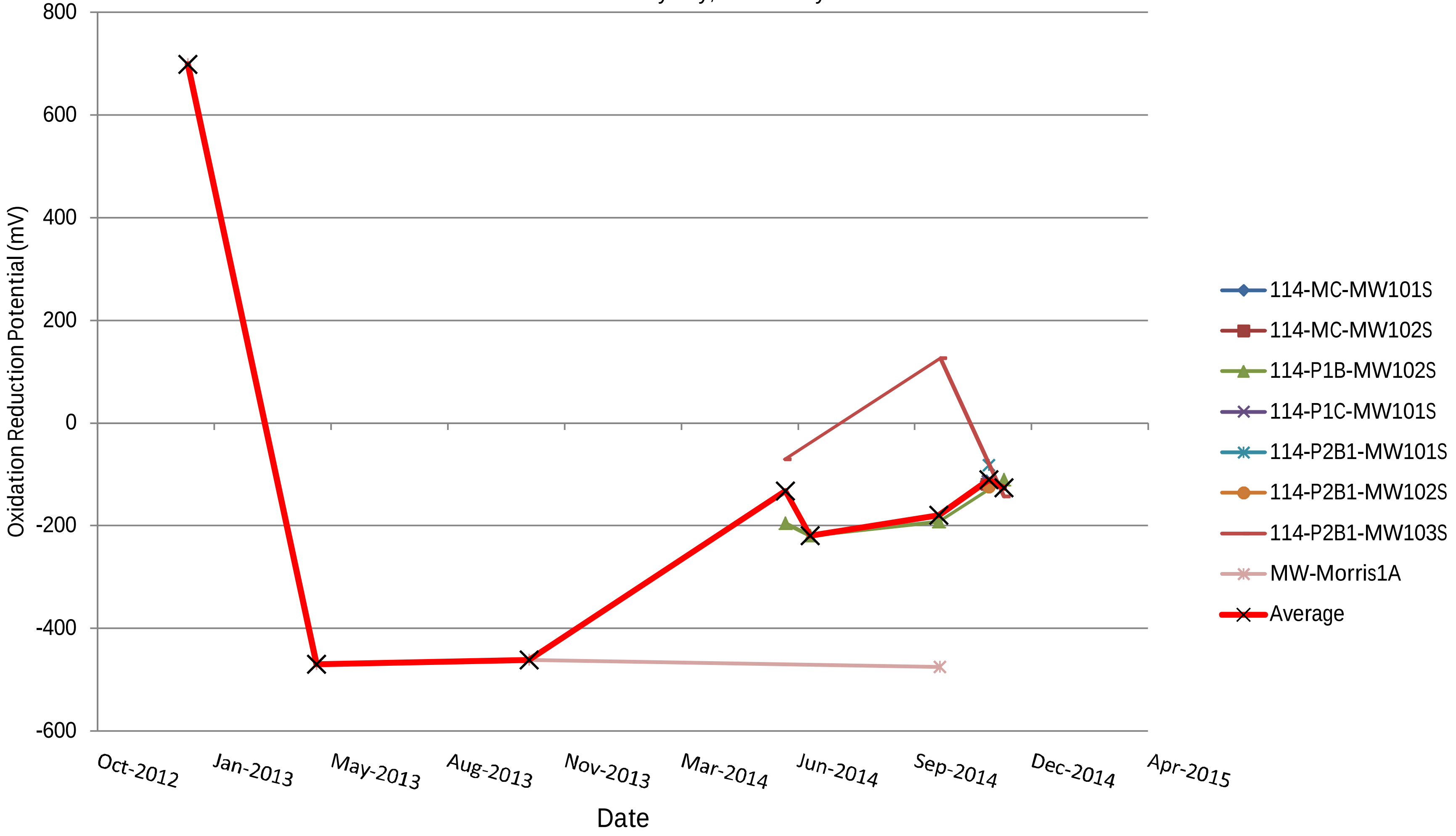
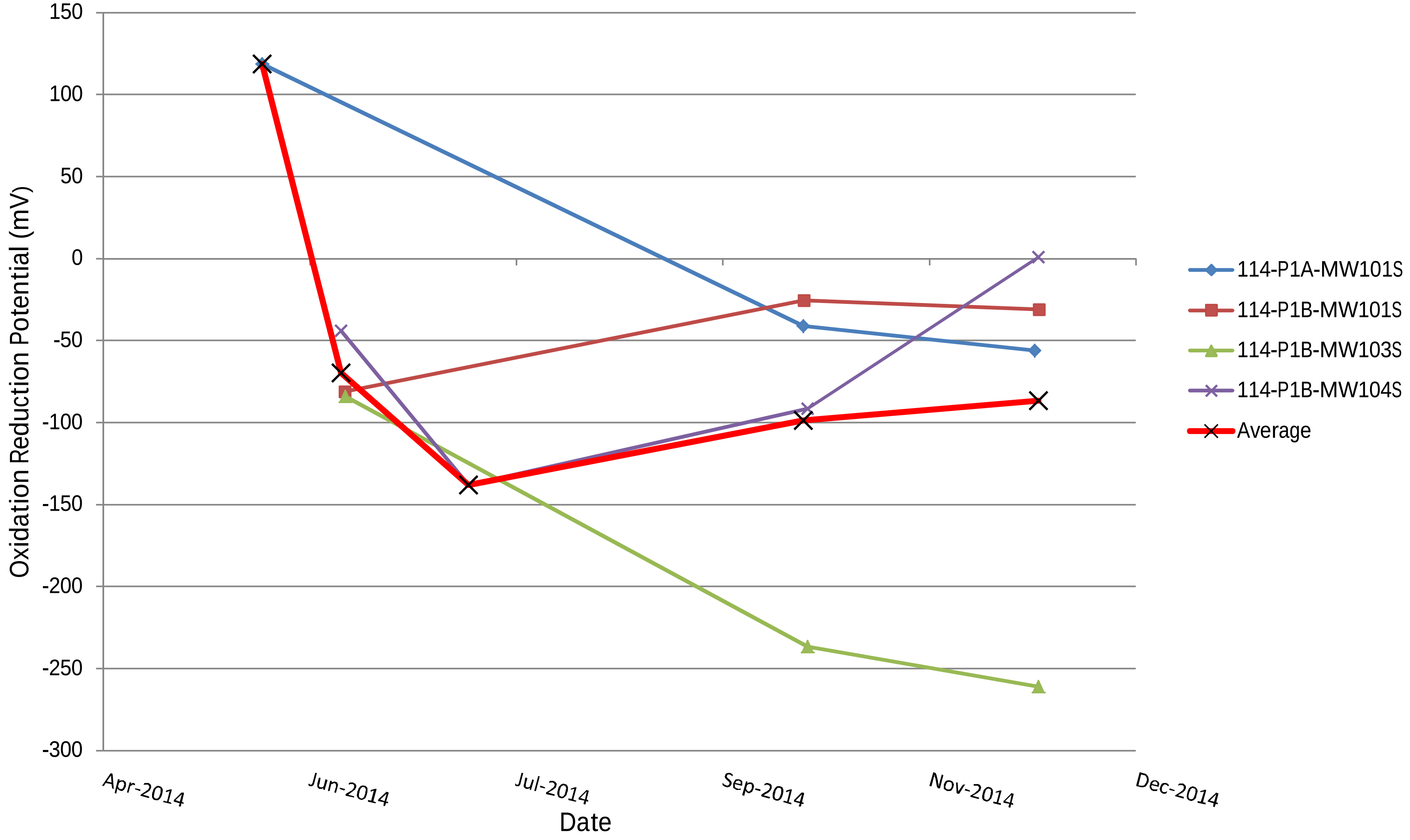


Figure 2G
Oxidation-Reduction Potential - Shallow Zone Groundwater
[Wells screened within FerroBlack-H amended backfill]
GA Group of Sites – PPG Industries, Inc.
Jersey City, New Jersey

Figure 2H
Oxidation-Reduction Potential - Shallow Zone Groundwater
[Wells screened outside FerroBlack-H amended backfill]
GA Group of Sites – PPG Industries, Inc.
Jersey City, New Jersey



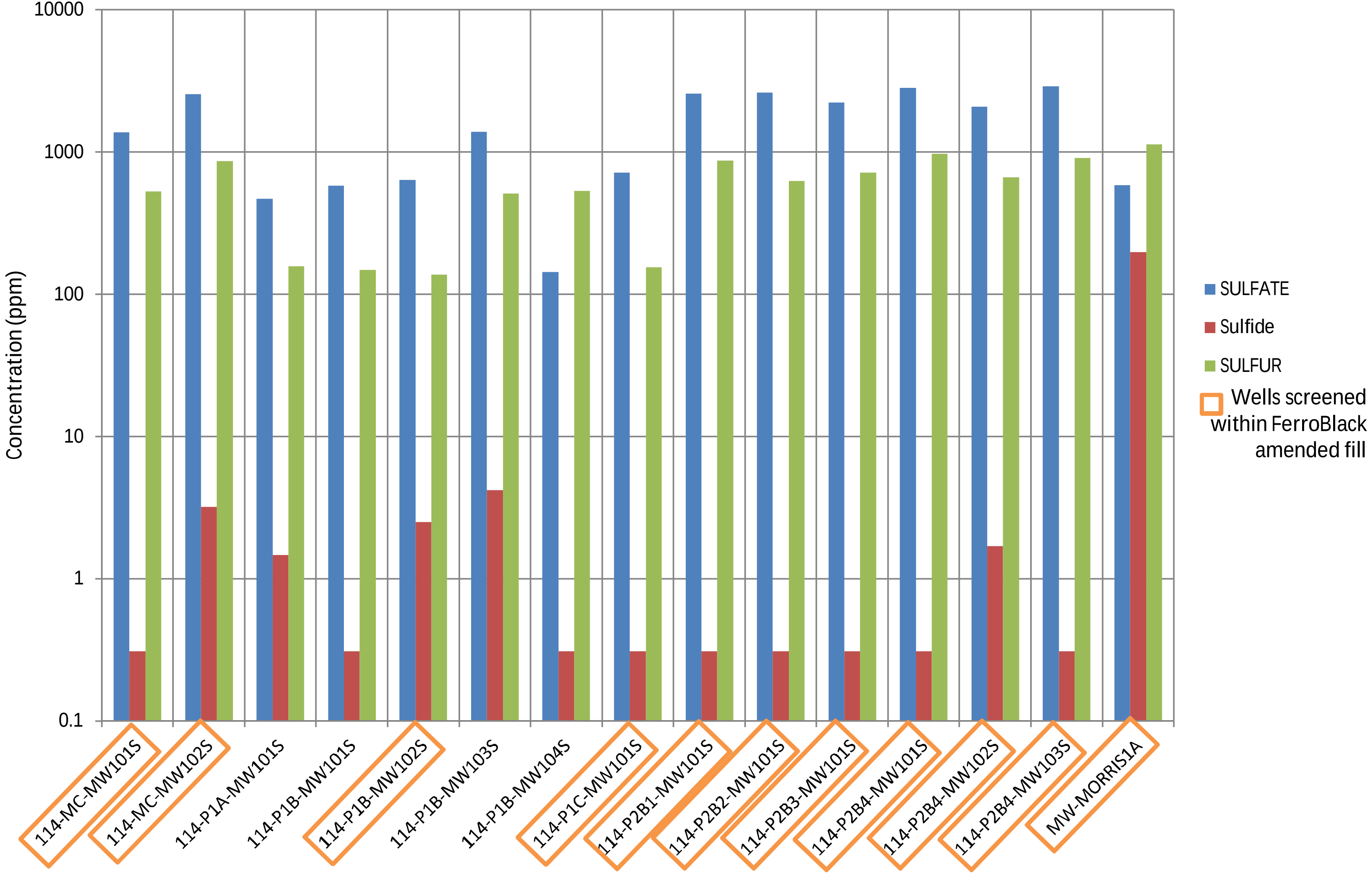


Figure 2I
Sulfur species (Unfiltered) in Shallow Groundwater (March/April 2015)
GA Group of Sites - PPG Industries, Inc.
Jersey City, New Jersey

ATTACHMENT B

In-Situ Chemical Reduction of Hexavalent Chrome at Chromite Ore Processing Residue Sites – Richard Brown, Ph.D., Leland Carlblom, Ph.D., Rick Jacobs, Gordon Post (May 2008).

Presented at Sixth International Battelle Conference
Remediation of Chlorinated and Recalcitrant compounds – May 2008

In-Situ Chemical Reduction of Hexavalent Chrome at Chromite Ore Processing Residue Sites

Richard. Brown, Ph.D. **(dick.brown@erm.com)** (ERM, Ewing, NJ)
Leland Carlblom, Ph.D., Rick Jacobs, Gordon Post (PPG Industries, Inc. Pittsburgh, PA)

ABSTRACT: In-situ Chemical Reduction (ISCR) converts mobile, toxic hexavalent chromium (Cr VI) to immobile, essentially non-toxic trivalent chromium (Cr III) and is used at sites contaminated by historical plating, wood treating, and tannery operations. ISCR can be a cost effective alternative to the excavation and disposal of hazardous soils and long term pump and treat remediation programs. In-situ Cr VI reduction has not been used at sites contaminated with Chromite Ore Processing Residue (COPR) because the geochemical and mineralogical nature of COPR makes the kinetics of chromium reduction at these sites very challenging despite its success in other applications.

One of the unique problems associated with treating COPR is the long-term release of the chromate that is bound in the mineral matrix. More than 90% of the Cr VI may be chemically bound in the matrix where it is not readily physically accessible for reduction by a soluble reductant. For example, chromate can exchange with sulfate in mineral matrices. It can be re-released by exchange with sulfates, phosphates or carbonates displacing Cr VI from the matrix into the pore water.

Addressing the mineral-bound Cr VI in COPR wastes is important for long term treatment efficacy. Unreacted Cr VI in the mineral matrix may slowly release into the surrounding pore water causing recurrence of dissolved chromium in the groundwater. The efficacy of Cr VI reduction can be enhanced by the use of a chromate release agent and by the inclusion of an insoluble reductant to the reagent mix. Maintaining residual reductant can address any Cr VI that is slowly released. The optimum reagent mix for treating Cr VI at COPR sites is, therefore, a blend of chromate release agent, a soluble, fast reacting reductant to address soluble Cr VI, and an insoluble reductant that will persist in the treated matrix. The target redox conditions for the treated material should be an $Eh < 0$ mV ($ORP < -200$ mV), and a $pH > 12$.

INTRODUCTION

Hexavalent chromium (Cr VI) is a ubiquitous environmental problem, found at 1,036 of the 1,591 National Priority List (NPL) sites identified by the USEPA in 2001. It is listed 18th on the CERCLA 2007 Priority List of Hazardous Substances, which is based on an algorithm incorporating frequency of occurrence at CERCLA NPL sites, toxicity, and potential for human exposure. Cr VI is classified by the World Health Organization and the USEPA as a human carcinogen, primarily through inhalation. Cr VI is highly mobile and can enter into water systems where it presents an inhalation and ingestion risk. The EPA's current maximum contaminant level (MCL) for total chromium is 100 µg/L (0.1 mg/L).

Hexavalent chromium is widely used in industry for metal plating, corrosion resistance coatings, production of dyes and paints, leather tanning, and wood treating. It is also produced in the manufacturing of stainless steels. Sites contaminated with Cr VI because of these types of operations display Cr VI distributions primarily in pore water and groundwater. Sites contaminated by former chromite ore processing facilities display a radically different distribution of Cr VI. The chromium distribution is quite complex occurring in both water and the COPR mineral matrix present at these sites.

Chromate and bichromate salts were historically produced by a process of high-lime roasting and extraction of chromite ore. The spent COPR contained high concentrations of Cr III and Cr VI with a typical pH in the 11 to 13 range. The Cr VI in COPR can leach over time into groundwater. Typical minerals found in COPR include chromite, sjogrenite, magnesioferrite, calcite, hydrogarnet, ettringite, brownmillerite, and portlandite. Some of these minerals can incorporate Cr VI in their geochemical lattices (Hillier, 2007; Geelhoed, 2003). In some COPR-soil mixtures, more than 90% of the Cr VI can be chemically bound into the mineral matrix. Table 1 postulates incorporation of chromate into typical COPR minerals. Chromate exchanged minerals can leach chromate to groundwater over time:

TABLE 1. Chromate incorporation into COPR related minerals

Mineral	Formula	Chromate Exchanged Mineral
Ettringite	$Ca_6Al_2(SO_4)_3(OH)_{12}\cdot 26(H_2O)$	$Ca_6Al_2(SO_4)_{3-x}(CrO_4)_x(OH)_{12}\cdot 26(H_2O)$
Magnesioferrite	$MgFe^{3+}{}_2O_4$	$MgFe^{3+}{}_2O_{4-x}(CrO_4)_x$
Brownmillerite	$Ca_2Al_{1.1}Fe^{2+}{}_{0.9}O_5$	$Ca_4Al_2Fe^{+3}(OH)_{19-x}(CrO_4)_x$
Hydrocalumite	$Ca_2Al(OH)_{6.5}C_{l0.5}\cdot 3(H_2O)$	$Ca_2Al(OH)_{6.5-x}C_{l0.5}(CrO_4)_x\cdot 3(H_2O)$
Sjogrenite	$Mg_6Fe^{3+}{}_2(CO_3)(OH)_{16}\cdot 4(H_2O)$	$Mg_6Fe^{3+}{}_2(CO_3)(OH)_{16-2x}(CrO_4)_x\cdot 4(H_2O)$
Portlandite	$Ca(OH)_2$	$Ca_2(OH)_2(CrO_4)$
Hydrogarnet	$Ca_3Al_2(SiO_4)_{1.5}(OH)_6$	$Ca_3Al_2(SiO_4)_{1.5}(OH)_{6-2x}(CrO_4)_x$
Chromite	$Fe^{2+}Cr_2O_4$	$Na_{3x}Fe^{3+}{}_x(CrO_4)_{3x}$

$$Ca_2Al(OH)_{4.5}Cl_{0.5}(CrO_4)\cdot 3(H_2O) + 2(OH^-) \rightarrow Ca_2Al(OH)_{6.5}Cl_{0.5}\cdot 3(H_2O) + CrO_4^{-2} \qquad (1)$$

The incorporated chromate can also be displaced by sulfate, phosphate or carbonate:

$$Ca_6Al_2(SO_4)_2(CrO_4)(OH)_{12} + SO_4^{-2} \rightarrow Ca_6Al_2(SO_4)_3(OH)_{12} + CrO_4^{-2} \qquad (2)$$

COPR can impact groundwater over significant areas. It was stored and disposed at chrome processing sites and was often also used locally as a fill material, which led to the multiplication of COPR impacted sites. Hudson County, NJ, which was home to three chrome processing plants, has over 160 COPR impacted sites (NJDEP, 2007).

While Cr VI is a ubiquitous environmental problem, it is, in some cases, relatively easy to treat. ISCR is a proven, effective technology for treatment of Cr VI in soil and groundwater at contaminated sites that were impacted by chromate salts from former metal plating, wood treating and tannery operations. Cr VI is a strong oxidant and is easily converted to immobile, non-toxic Cr III through chemical or biological reduction. In situ reduction is an effective alternative to costly excavation and disposal of hazardous chromium impacted soils, and to the long term operation of pump and treat systems to address dissolved chromium. However, as will be discussed, the geochemical and mineralogical nature of COPR makes the application of chrome reduction very challenging.

The nature of the distribution of chromate between soil and pore water varies with the source(s) of the chromium. Chromate is bound and distributed very differently in COPR containing soils than in native, non-COPR containing soil. The total distribution of Cr VI can be described generically as

$$\text{Cr VI}_{total} = \text{Cr VI}_{bound} + \text{Cr VI}_{adsorbed} + \text{Cr VI}_{pore\ water} \qquad (3)$$

This distribution varies between COPR impacted soils and non-COPR soils and affects the ease and efficacy of treatment. COPR soils have a higher proportion of bound Cr VI.

MATERIALS AND METHODS

Two types of soil composite samples were used for this study. One contained COPR; the other did not. Both samples were obtained from PPG's former manufacturing plant located at 900 Garfield Avenue site in Jersey City, NJ. The COPR containing, field moist sample contained 3600 mg/Kg of Cr VI, and the non-COPR sample contained 1800 mg/Kg Cr VI. Analysis of pore water from the samples indicated that 2% of the total Cr VI in the COPR containing soil was in the pore water; 98% was bound or adsorbed, whereas 80% of the total Cr VI in the non-COPR soil was in the pore water and only 20% was bound or adsorbed.

Batch and Column studies were conducted to elucidate the response of COPR containing soils to chemical reduction and to determine the optimal treatment protocol.

RESULTS AND DISCUSSION

Hexavalent chromium is a strong oxidant and is, therefore, relatively easy to reduce. A range of Cr VI reductants are described in the literature, the most common of which are Fe II and sodium or calcium polysulfide. Solid reductants such as zero valent iron amorphous FeS, have also been shown to be effective (Patteson, 1997), presumably due to reaction of Cr VI at the particle liquid interface **(**Boursiquot, 2002). Not all reductants , however, are applicable to COPR. Soluble Fe II salts, such as ferrous sulfate, are effective at low pH conditions (Buerge, 1997). However, the high pH conditions of COPR (pH 12-13) preclude the use of Fe II due to the formation and low solubility of $Fe(OH)_2$. Calcium polysulfide has been shown to be effective for COPR remediation in several studies (Boursiquot, 2002; Wazne, 2007; Graham, 2006). Based on their reported efficacy, FeS and calcium polysulfide were chosen for further study.

Reduction Chemistry and Reaction Kinetics of Cr VI in COPR Soil. Dosing ratios for the two reductants were determined by a visual end point of no persistent color (estimated to be <5 mg/L by comparison to lab standards). Water containing 250 mg/L of Cr VI was adjusted to a pH of 8.5 or 12. The 8.5 pH value was chosen for non-COPR soil and 12.0 for COPR soil. The two solutions were then dosed with increasing ratios of the two reductants and allowed to equilibrate. The stoichiometric ratio was the lowest reductant dosage level which showed no persistent yellow color after equilibration. The dosages measured are shown in Table 2. As can be seen, FeS requires more time to react, but is a more efficient reductant than polysulfide. A surprising result was the lower dosage requirement observed for polysulfide at the high pH (12.0). This result,

TABLE 2. Reductant to Cr VI Ratios, (wt/wt). Equilibrium times in parentheses.

Reductant	pH 8.5	pH 12.0
CaS_x	6 (2-3 wks)	3 (4-6 wks)
FeS	2.5 (6-8 wks)	2.5 (6-8 wks)

not previously reported in chromate reduction studies, could be due to the reaction of freshly precipitated sulfur with hydroxyl ion to regenerate sulfur based reducing species (Kleinjan, 2005). The qualitative difference in reaction rate observed for polysulfide at the two pH values is consistent with kinetic studies of Cr VI reduction by polysulfide which showed a marked pH effect upon rate (Kim, 2001).

The effect of pH upon polysulfide reaction kinetics with Cr VI was further examined. Chromate at 250 mg/L was dosed with 0.25 equivalents of CaS_x. The reaction was followed by tracking the Eh of the solution. The disappearance of polysulfide (S_x^{-2}) over time was estimated from the Eh data as a function of reaction pH. Estimated reactions times at pH values of 3.0, 8.8, and 12^+ were 2, 17, and 1600 minutes respectively. These reactions were run with the exclusion of air.

These large differences in reaction rate as a function of pH have critical implications for the analysis of Cr VI in high pH samples containing reductant when the analysis procedure involves adjustment to lower pH (e.g. Method 3060). The lowering of the pH increases the rate of reaction, driving the reduction reaction further to completion, resulting in a lower than the actual residual Cr VI level.

Given the slow rate of reaction of polysulfide with chromate at high pH, the effect of adding excess reductant was examined. At stoichiometry, the reaction kinetics are dependent on the concentration of both the reductant and the chromate:

$$-d[Cr^{+6}]/dt = k_1\,[Cr^{+6}]^x\,[R]^y \qquad (4)$$

At an excess level of reductant in COPR soil (where the Cr VI level in the pore water is low) the kinetics becomes pseudo-first order in Cr VI:

$$-d[Cr^{+6}]/dt = k_2\,[Cr^{+6}]^x \quad \text{where } k_2 = k_1\,[R]^y \qquad (5)$$

The rate of reduction is thus controlled by the rate of release of chromate from the COPR matrix. This suggests that the use of an anion exchange agent, coupled with excess reductant would be an effective mixture for the treatment of COPR.

The disappearance of polysulfide by itself over time in the presence of air was measured at a pH 12.0, in the absence of chromate. The reaction time was 210 minutes, eight times faster than the reaction of polysulfide with chromate. This indicates that the availability of oxygen will have an important effect upon efficiency of chromate reduction at high pH. Over time, the polysulfide is oxidized and there is no residual left to react with Cr VI that may be released from the COPR minerals. This suggests the benefit of adding a persistent reductant.

Chromate Binding and Release in Different Soil Types. Water was mixed with field-moist soil in ratios ranging from 0 (undiluted soil) to 20. The measured Cr VI concentration released from the soil after dilution and 1 week aging was compared to the calculated value for two models. One model was a simple dilution model which calculated chromate concentration in supernatant water as a function of increasing water dilution, assuming that the amount of chromate in the pore water is diluted by added water and that no additional chromate is released from the soil as water is added. A simplified desorption model was also used (Dragun, 1988) as calculated from the expression:

$$K_d = C_s/C_w \text{ , where } C_s = \text{gm Cr VI/Kg soil and } C_w = \text{gm Cr VI/L water} \qquad (6)$$

The measured and calculated data are shown in Figure 1 for COPR soil and Figure 2 for non-COPR soil. The COPR soil seems to follow the dilution model (Figure 1) indicating that no further chromate is released over the span of the one week equilibrium time, suggesting the chromate is strongly bound and release from COPR soils is slow. The non-COPR soil results are consistent with both models indicating that desorption from non-COPR soils is very rapid. Washing with fresh water immediately desorbs any remaining chromate in the soil. The chromate is not tightly bound in the non-COPR soil.

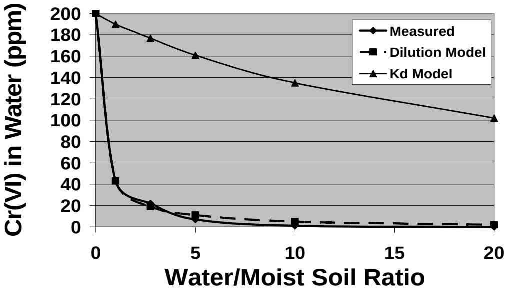


FIGURE 1 - Chromate concentration in supernatant water as a function of increasing water dilution, COPR Soil

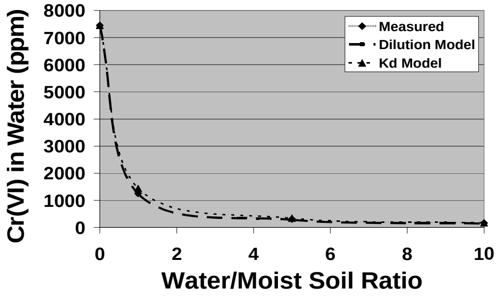


FIGURE 2 - Chromate concentration in supernatant water as a function of increasing water dilution, non-COPR Soil

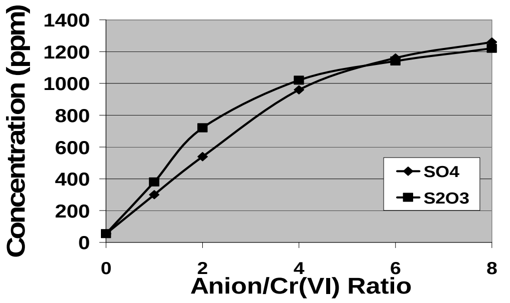


FIGURE 3 – Anion Exchange characteristics of sulfate and thiosulfate.

Literature studies have indicated that leachable chromate in COPR materials is ionically bound in the mineral as Ca(II), Al(III), or Mg(II) salts (Moerman, 1996) or is bound in the interlayers of layered double-hydroxide minerals such as hydrocalumite (Geelhoed, 2003). These same studies have shown that the addition of anions such as sulfate can release chromate by anion exchange. Sodium sulfate and sodium thiosulfate were tested as exchange agents in the COPR soil. Sodium thiosulfate was studied since it is the reaction product of polysulfide with oxygen. The results of the addition of sodium sulfate and sodium thiosulfate to COPR soil are shown in Figure 3. Solution to moist soil ratios (wt/wt) were 2.5, and equilibration times were 12 days. The Anion to Cr VI ratio was varied. As noted in the cited literature references, the effect of sodium sulfate upon chromate release in COPR soil is significant. The addition of either anion at an anion to Cr VI weight ratio of 6.0 increases the amount of Cr VI in solution by about a factor of 20. The effect of thiosulfate on desorbing chromate suggests that

TABLE 3 – Experimental plan for batch and column testing of reductant combinations and levels

Run #	Reductant Type	Reductant Level	AEA Type
1	COPREX	2.5X	---
2	COPREX	5X	---
3	COPREX	7.5X	---
4	COPREX	7.5X	SO_4
5	COPREX/FeS	1.5X/1X	---
6	COPREX/FeS	3X/2X	---
7	COPREX/FeS	4.5X/3X	---
8	COPREX/FeS	1.5X/1X	SO_4
9	CaSx	2.5X	---
10	CaSx	5X	---
11	CaSx	7.5X	---
12	COPREX/FeS	4.5X/3X	---
13	---	---	NA

polysulfide may be a powerful treatment tool, being both a strong reductant and a release agent.

Use of Reductant Mixtures for ISCR of Cr VI in COPR Soil. The optimum reagent mix for ISCR of Cr VI at COPR sites is a blend of a mobile, fast reacting reductant to address soluble Cr VI and an immobile reductant that will persist in the treated matrix. A material capable of speeding release of Cr VI from the COPR matrix should also be included. Reagents should be applied at an appropriate stoichiometric excess to improve release and reaction kinetics, to maximize mixing efficiency while minimizing excess water, and to provide residual reduction conditions. The target redox conditions for the treated material should be Eh < 0 mV (ORP < -200 mV), and a pH > 12. This reagent testing used CaS_x, COPREX^{TM} ($NaCaS_x$), and FeS (COPREX^{TM} and FeS are products of Redox Solutions, LLC). A fractional factorial experimental design was used to compare reductants and equivalence levels for both batch and column testing (Table 3). Sulfate was added to two of the runs as a potential anion exchange agent (AEA) (sulfate:Cr = 4.0 wt/wt).

Lab Batch Test Results. Lab batch testing utilized 25 g. soil samples, which were dosed with the reductant solutions as received. Air was purged from the headspace by a nitrogen gas flush. The results of lab batch testing after storage for 5 days and 55 days are shown in Table 4. AD (alkaline digestion) refers to Cr VI determination by USEPA Methods 3060 and 7196 using a heated, high-pH extraction followed by colorimetric analysis at a low pH. SPLP (synthetic precipitation leach procedure) refers to total Cr determination by USEPA Methods 1312 and 6010. "Wash + AD" refers to washing with water (L:S ratio of 20) by overnight agitation on a wrist shaker, followed by filtration, and analysis by the AD procedure. The purpose of the wash was to remove residual soluble reductant to get a true value for residual, unreduced Cr VI, since the heating and pH reduction steps of Method 3060 will continue to cause chromate reduction until all residual reductant has been consumed.

Table 4 - Lab Batch Results

Run #	Description	5 Day Reaction Time AD mg/Kg	 SPLP mg/L	 Wash + AD mg/Kg	55 Day Reaction Time AD mg/Kg	 SPLP mg/L	 Wash + AD mg/Kg
1	COPREX, 2.5X	ND	<0.2	402	ND	<0.2	297
2	COPREX, 5X	ND	<0.2	237	ND	<0.2	36
3	COPREX, 7.5X	ND	<0.2	199	ND	<0.2	ND
4	COPREX, 7.5X + SO_4	ND	<0.2	592	ND	<0.2	30
5	COPREX/FeS, 1.5X/1X	ND	5.7	545	ND	4.0	889
6	COPREX/FeS, 3X/2X	ND	<0.2	16	ND	<0.2	264
7	COPREX/FeS, 4.5X/3X	ND	<0.2	ND	ND	<0.2	ND
8	COPREX/FeS, 1.5X/1X + SO_4	ND	<0.2	294	ND	0.6	432
9	CaS_x, 2.5X	ND	9.0	513	ND	3.80	354
10	CaS_x, 5X	ND	<0.2	119	ND	<0.2	294
11	CaS_x, 7.5X	ND	<0.2	49	ND	<0.2	54
12	COPREX/FeS, 4.5X/3X	ND	<0.2	ND	ND	<0.2	ND
13	untreated control	4639	11.2	4278	---	---	---

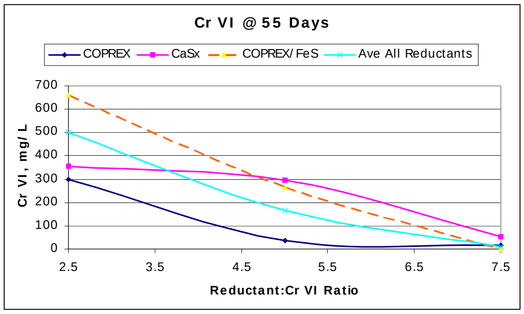


FIGURE 5: Effect of Reductant to Cr VI Ratio

Several observations can be made from the data in Table 4. First, the ratio of reductant to Cr VI is important; generally the higher the ratio, the lower the resulting Cr VI (e.g., Runs 1-3, 5-7, and 9-11). This is depicted in Figure 5. The type of reductant also has an effect especially at the lower ratios. COPREX appears to be the most efficient reductant. However, at the highest reductant ratio the type of reductant does not appear important. The effect of added sulfate is hard to decipher. This may be due to the effect of thiosulfate, the reaction product of polysulfide, also acting as an anion exchange agent and "overpowering" the effect of sulfate, the addition of more anion exchange agent had little further effect. The data also suggests that there is a slow release of Cr VI from the COPR soils. The 5 vs. 55 day "Wash + AD" results suggest that the last 5-10% of Cr VI is slow to release, reinforcing the need for a non-leachable reductant (FeS) to maintain reduction capability.

Column Test Results. Column testing was performed by SECOR International, Inc. (a Stantec company). Soil was treated and allowed to equilibrate for 5 days prior to packing into columns. The columns had a total volume of about 12,000 mL, with a pore volume of about 3500 mL. Simulated rainwater was pumped through the columns at a rate of 1.2 mL/min or one pore volume every 2 days. The tests were run until 25 pore volumes had passed through each column (50 days), simulating 30-50 years of groundwater flow at the site. Column leachate was tested for Cr VI, pH, and ORP as a function of pore volumes. Cr VI was only detected in the leachate from the untreated soil column (column 13). All leachate pH values remained in the 12-13 range. The ORP of the leachate samples showed some increase as a function of pore volumes, but correlated well with the initial amount of soluble reductant (CaS_x or COPREX™) in the treated soil.

Column soils were tested for Cr VI by AD and for total Cr by SPLP before leaching and after 25 pore volumes. The results are summarized in Table 5. Cr VI results for all treated soils were non-detect (ND) and SPLP results for treated soils (except for those containing sulfate) were less than the EPA drinking water standard of 0.1 mg/L. The ORP values of the treated soils after 25 pore volumes of water leaching were still well within the reducing region for Cr VI. Even columns with the lower level polysulfide treated soils retained sufficient reductant to maintain reducing conditions. Only the lowest level of soluble reductant (Runs 5 and 8) showed any leachable Cr VI by SPLP, and only at the initial time point. The column results demonstrate the stability of the treated soils.

Table 5 - Column Test Results

Run #	Description	Initial AD mg/Kg	Initial SPLP mg/L	Initial ORP mV	After 25 Pore Volumes AD mg/Kg	After 25 Pore Volumes SPLP mg/L	After 25 Pore Volumes ORP mV
1	COPREX, 2.5X	ND	<0.05	-500	ND	<0.05	-460
2	COPREX, 5X	ND	<0.05	-510	ND	<0.05	-450
3	COPREX, 7.5X	ND	<0.05	-520	ND	<0.05	-500
4	COPREX, 7.5X + SO_4	ND	<0.05	-530	ND	<0.05	-440
5	COPREX/FeS, 1.5X/1X	ND	0.10	-490	ND	<0.05	-430
6	COPREX/FeS, 3X/2X	ND	<0.05	-540	ND	<0.05	-510
7	COPREX/FeS, 4.5X/3X	ND	<0.05	-550	ND	<0.05	-500
8	COPREX/FeS, 1.5X/1X + SO_4	ND	0.65	-400	ND	<0.05	-440
9	CaS_x, 2.5X	ND	<0.05	-490	ND	<0.05	-450
10	CaS_x, 5X	ND	<0.05	-500	ND	<0.05	-500
11	CaS_x, 7.5X	ND	ND	-520	ND	<0.05	-430
12	COPREX/FeS, 4.5X/3X	ND	<0.05	-550	ND	<0.05	-480
13	untreated control	3630	5.00	-190	2900	2.80	-180

CONCLUSIONS

This work clarifies the in situ reduction of Cr VI in COPR soil. The following conclusions can be made: 1.) Cr VI is physically/chemically bound to COPR matrix such that its release is very slow upon exposure to groundwater flow. 2.) The inherent rate of the reduction reaction by typical reductants is slow at COPR pH conditions. Use of an excess of reductant will help the overall speed of reaction by making the kinetics pseudo-first order in Cr VI. The overall rate is then expected to be controlled by the rate of Cr VI release from the COPR matrix. The rate of release can be accelerated by the introduction of materials which can ion exchange for chromate, either in the form of added chemicals, or chemicals inherently present in the reductant chemicals, or products of the reductant/chromate reaction. 3.) A compromise between reaction speed and long term persistence of reducing conditions can be achieved by a mix of soluble, mobile reductant and insoluble, immobile reductant. Even though the column simulation of 30-50 years of groundwater flow left sufficient soluble reductant in the soil to maintain reducing conditions at the lowest reductant dosage, the more aggressive leaching conditions of the batch testing sample wash demonstrate the more robust reductant mix to be a combination of soluble and insoluble reductants at a relatively high dosage. 4.) Analysis for Cr VI in reductant treated soil samples can yield values for Cr VI which are lower than the actual sample when residual reductant is present. Washing out the residual reductant prior to analysis improves the accuracy of the Cr VI results.

References

NJDEP 2007. http://www.state.nj.us/dep/srp/siteinfo/chrome/bkgrnd.htm

Hillier, S., Lumsdon, D.G., Brydson, R., and Paterson, E. February 2007. "Hydrogarnet: A Host Phase for Cr VI in Chromite Ore Processing Residue (COPR) and Other High pH Wastes." *Environ. Sci. Technol.*, 41 (6), 1921 -1927.

Geelhoed, J.S., Meeussen J., Roe, M. J., Hillier, S., Thomas, R.P., Farmer, J.G., and Patterson, E. 2003. "Chromium Remediation or Release? Effect of Iron(II) Sulfate Addition on Chromium(VI) Leaching from Columns of Chromite Ore Processing Residue." *Environ. Sci. Technol.* 2003, 37, 3206-3213.

Dragun, J. 1988. *The Soil Chemistry of Hazardous Materials*. The Hazardous Materials Control Research Institute.

Moerman. 1996. "Advanced Characterization and Leaching Behavior of Hexavalent and Trivalent Chromium from Waste Material" M.S. Thesis, NJ Institute of Technology, Newark, N.J.

Buerge, I..J. and Hug, S.J. 1997. "Kinetics and pH Dependence of Chromium(VI) Reduction by Iron(II)." *Environ. Sci. Technol.*, 31(5), 1426-1433.

Patteson, R.R. and Fendorf, S. 1997. "Reduction of Hexavalent Chromium by Amorphous Iron Sulfide." *Environ. Sci. Technol.* 31(7), 2039-2044.

Boursiquot, S., Mullet, M., and Ehrhardt, J. 2002. "XPS Study of the Reaction of Cr (VI) with Mackinawite (FeS)." *Surface and Interface Analysis*, 34, 293-297.

Wazne, W., Moon, D.H., Jagupilla, S.C., Christodoulatos, C., Dermatas, D., and Chysochou, M. 2007. "Remediation of Chromite Ore Processing Residues Using Ferrous Sulfate and Calcium Polysulfide." *Geosciences J.*, 11(2), 105-110.

Graham, M.C., Farmer, J.G., Anderson, P., Paterson, E., Hillier, S., Lumsdon, D.G., and Bewley, R.J.F. 2006. "Calcium Polysulfide Remediation of Hexavalent Chromium Contamination from Chromite Ore Processing Residue." *Sci. of the Total Environ.*, 364(1-3), 32-44.

Kleinjan, W. E., Keizer, A.D., and Janssen, A.J.H. 2005. "Kinetics of the Chemical Oxidation of Polysulfide Anions in Aqueous Solution." *Water Research*, 39, 4093-4100.

Kim, C., Zhou, Q., Deng, B., Thornton, E.C., and Xu, H. 2001. "Chromium(VI) Reduction by Hodrogen Sulfide in Aqueous Media: Stoichiometry and Kinetics" *Environ. Sci. Technol.*, 35, 2219-2225

AECOM

ATTACHMENT C

LONGEVITY EVALUATION FOR FERROBLACK®-H AMENDED BACKFILL SOILS

JUNE 16, 2017

Prepared By:

Sachin Sharma

Sachin Sharma, PE, AECOM

Shree Ravi

Shree Ravi, EIT, AECOM

Reviewed By:

Lucas Hellerich

Lucas Hellerich, Ph.D., P.E., LEP, AECOM

Attachment C
Longevity Evaluation for FerroBlack®-H Amended Backfill Soils
Garfield Avenue Group of Sites
PPG, Jersey City, New Jersey

Estimation of FerroBlack®-H Longevity at IRM #1 (0.7% Amendment Area)

Data Input Cell
Variables for each phase
Data Output Cell

This FerroBlack®-H longevity estimate assumes the following:

The annual Cr^{+6} groundwater flux is constant and is based on the most current groundwater and soil concentration data;
The upward migration of Cr^{+6} in groundwater is subject to retardation, which is estimated from the apparent partitioning calculated as the ratio of the soil and aqueous chromium concentrations;
The Cr^{+6} and dissolved oxygen (DO) will be the primary oxidizing constituents of the reductants in FB-H; and
The vertical hydraulic conductivity is assumed to be 10% of the horizontal hydraulic conductivity.

Intermediate Zone Aquifer Properties	**Values**	**Calculations**	**Units/Description**
Horizontal Hydraulic Conductivity, Kh	3.80	NA	ft per day, used value from 114-MW19B (Phase 3C, meadow mat present)
Vertical Hydraulic Conductivity, Kv	0.38	NA	ft per day, assumed 10% of Kh (Reference: Groundwater Hydrology [2nd ed.] by D. K. Todd. Wiley, New York, 1980. 552 pp.)
Average Vertical Hydraulic Gradient (I)*	-0.0085	Groundwater flow is downward	ft/ft, based on the transducer data from June 2016 to December 2016 for Phase 1C (nearest)
Soil Bulk Density,ρb	1.62	NA	ton/cy, based on the values used in the approved groundwater pilot study Permit-By-Rule (PBR) application. Discharge Approval and Monitoring Requirement Associated with Permit-By-Rule Discharge Authorization for PPG Industries (COPR) (NJDEP, 2015)
Total Porosity, θT	30%		percentage, same reference as mentioned above (NJDEP, 2015)
Area, A	1,435	NA	sf, Figure 3-4 of Site-Wide GW Summary Report - April 2015 through March 2016 (AECOM, 2016)
Upward Vertical Flow Rate, Qcf	0	Qcf=Kv*I*A, flow is downward only	cf/day
Upward Vertical Flow Rate, Q	0	Q=Kv*I*A*28.3168 liter/cf	Liters/day (appropriate unit conversions applied)
Oxidative Demand from Precipitation in Shallow Zone	**Values**	**Calculations**	
Annual Precipitation, P	46.42	NA	inches/year, reference: www.usclimatedata.com
Annual Infiltration Rate, i%	20%	NA	based on HELP modeling (Attachment E).
Annual Total Infiltration, I	31,430	I = (A*P*i%/12)*28.3168 liter/cf	Liters/year (appropriate unit conversions applied)
Dissolved Oxygen due to Precipitation, DO (Assumed from the Phase 2A area)	2.18		mg/L, an average DO from four shallow wells in Phase 2A area (unamended), measured in Dec. 2016, was used. These four wells are 114-P2A-MW101S, 114-P2A-MW102S,114-P2A-MW103S, and 114-P2A-MW104S.
Flux of Dissolved Oxygen from Precipitation, Fop	0.07	Fop= (DO*I)/10^6 mg/kg	kg/year (appropriate unit conversions applied)
Oxygen Demand for FB-H to Reduce 1 gram of Oxygen, ODF	40.37	NA	gm FB-H/gm O_2, per stoichiometry (Attachment F)
Annual Oxidative Demand from Precipitation, OS	2.8	OS =Fop*ODF	kg FB-H/year
Oxidative Demand from Intermediate Zone	**Values**	**Calculations**	
Dissolved Oxygen in Groundwater, Doi	0.09	NA	mg/L, June 2016 (114-P1A-MW101I)
Upward Flux of Dissolved Oxygen from Intermediate Zone, Foi	0.00	Foi=(Q*Doi/10^6)*365 days/year	kg/year
Cr^{+6} Concentration in Intermediate Zone	**Values**	**Calculations**	
Average Concentration of Cr^{+6} in Groundwater, Cg	12.6	NA	mg/L, average of last four quarters of data from 114-P1A-MW101I (September 2015 through June 2016)
Cr^{+6} Concentration (Highest) in Soil in Intermediate Zone, Cs	9.5	NA	mg/kg, 114-P1A-MW101I (33.5-34.0 ft)
Distribution coefficient, Kd	0.75	Cs/Cg	L/kg
Retardation Coefficient, Rf	5.82	Rf = 1+(ρb*(1.18655(gm/cc)/(ton/cy))/θT)*Kd	unitless (appropriate unit conversions applied)
Amended Backfill Soils	**Values**	**Calculations**	
FB-H Applied	6.1	NA	short tons, from field tracking logs
FB-H Applied	5,565	FB-H applied * 907.185 kg/ton	kg (appropriate unit conversions applied)
FB-H Amendment in the Soil Required to treat 1 gram of Cr^{+6} based on Stoichiometry, As	18.64	NA	gm FB-H/gm Cr^{+6}, per stoichiometry to reduce Cr^{+6} to Cr^{+3} (Attachment F)
Dosage of FB-H, X	0.007	NA	percentage by weight
Porosity of Dense Graded Aggregate (DGA), θ_{DGA}	0.26	NA	Reference: Capillary Break Design Report (GAG-036K) (AECOM, 2017)
Cr^{+6} concentration (pre-remediation) in the shallow zone	500.0	NA	mg/L, average concentrations from MW2A, MW9A
Amendment Depth	10.3	NA	ft
Mass of Cr^{+6} in open excavation reacting with FB-H	54	Area * Amendment depth * Cr^{+6} concentration * θ_{DGA} * (28.3168 L/ft^3) * (kg/10^6 mg)	kg (appropriate unit conversions applied)
Amount of FB-H exhausted by initial reaction with Cr^{+6}, FB-H Exhausted	1,014	(Mass of Cr^{+6} in excavation) * As	kg (appropriate unit conversions applied)
Remaining FB-H for long term reduction, FB-H Remaining	4,551	(FB-H Applied) - (FB-H Exhausted)	kg (appropriate unit conversions applied)
FB-H Longevity	**Values**	**Calculations**	
Flux of Cr^{+6} per year from Intermediate Zone, F	0.00	F =((Cg/Rf)*365 days/year*Q)/10^6 mg/Kg	flux of Cr^{+6} (kg/year) (appropriate unit conversions applied)
Flux of Oxygen from Shallow and Intermediate Zone per year, Fo	0.07	Fo = Foi+Fop	flux of DO (kg/year)
Duration of FB-H Longevity Based on Combined effect of Stoichiometric Demand for Cr^{+6} Flux and Oxygen Flux, Tf	**1,645**	Tf = FB-H Remaining/(As*F + ODF*Fo)	years, longevity based on combined effect of oxygen flux and Cr^{+6} flux, excluding FB-H initially exhausted
Minimum quantity of FB-H required to sustain for 100 years, W_{100}	**0.30**	W_{100} = 100*((As*F*0.0011 Ton/Kg) + (ODF*Fo*0.0011 Ton/Kg))	tons (appropriate unit conversions applied)
Minimum thickness of FB-H amended soils to sustain for 100 years, d_{100}	**0.51**	d_{100} = W_{100}/(A*ρb*X/27 cf/cy)	ft of amended soil (appropriate unit conversions applied)
Minimum quantity of FB-H required to sustain for 30 years, W_{30}	**0.09**	W_{30} = W_{100}*0.3	tons
Minimum thickness of FB-H amended soils to sustain for 30 years, d_{30}	**0.15**	d_{30} = d_{100}*0.3	ft of amended soil

Notes:
* A negative hydraulic gradient indicates downward flow, and a positive value indicates upward flow.
Units from conversion factors are provided with them and the units for the individual parameter are under the Units/Description column.

CCPW - chromate chemical production waste
cf - cubic feet
cf/day - cubic feet per day
ft - feet
FB-H - FerroBlack®-H
gm - grams
gm/gm - gram per gram
kg - kilograms
L/kg - liters per kilogram
mg/Kg - milligram per kilogram
mg/L - milligram per liter
NA - Not Applicable
sf - square feet
ton/cy - ton per cubic yard
cc - cubic centimeter
cy - cubic yard

References:
AECOM, 2017. GAG-036K: Draft Capillary Break Design Report. May.
AECOM, 2016. GW-006D: Site-Wide Groundwater Summary Report (April 2015 through March 2016). June.
NJDEP, 2015. Discharge Approval and Monitoring Requirement Associated with Permit-By-Rule Discharge Authorization for PPG Industries (COPR). June.
Todd, D.K., 1980. Groundwater Hydrology [2nd Edition]. Wiley, New York. 552 pp.

Estimation of FerroBlack®-H Longevity at Phase 1A (2.8% Amendment Area)

Data Input Cell
Variables for each phase
Data Output Cell

This FerroBlack®-H longevity estimate assumes the following:

The annual Cr^{+6} groundwater flux is constant and is based on the most current groundwater and soil concentration data;
The upward migration of Cr^{+6} in groundwater is subject to retardation, which is estimated from the apparent partitioning calculated as the ratio of the soil and aqueous chromium concentrations;
The Cr^{+6} and dissolved oxygen (DO) will be the primary oxidizing constituents of the reductants in FB-H; and
The vertical hydraulic conductivity is assumed to be 10% of the horizontal hydraulic conductivity.

Intermediate Zone Aquifer Properties	**Values**	**Calculations**	**Units/Description**
Horizontal Hydraulic Conductivity, Kh	0.86	NA	ft per day, geomean of the Kh values observed during tests in Phase 1A
Vertical Hydraulic Conductivity, Kv	0.09	NA	ft per day, assumed 10% of Kh (Reference: Groundwater Hydrology [2^{nd} ed.] by D. K. Todd. Wiley, New York, 1980. 552 pp.)
Average Vertical Hydraulic Gradient (I)*	0.0039	Groundwater flow is upward for a small duration, hence an upward gradient is considered for calculations for a conservative estimate.	ft/ft, based on the transducer data from June 2016 to November 2016.
Soil Bulk Density,ρb	1.62	NA	ton/cy, based on the values used in the approved groundwater pilot study Permit-By-Rule (PBR) application. Discharge Approval and Monitoring Requirement Associated with Permit-By-Rule Discharge Authorization for PPG Industries (COPR) (NJDEP, 2015)
Total Porosity, θT	30%	NA	percentage, same reference as mentioned above (NJDEP, 2015)
Area, A	19,715	NA	sf, Figure 3-4 of Site-Wide GW Summary Report - April 2015 through March 2016 (AECOM, 2016)
Upward Vertical Flow Rate, Qcf	7	Qcf=Kv*I*A	cf/day
Upward Vertical Flow Rate, Q	186	Q=Kv*I*A*28.3168 liter/cf	Liters/day (appropriate unit conversions applied)
Oxidative Demand from Precipitation in Shallow Zone	**Values**	**Calculations**	
Annual Precipitation, P	46.42	NA	inches/year, reference: www.usclimatedata.com
Annual Infiltration Rate, i%	20%	NA	based on HELP modeling (Attachment E).
Annual Total Infiltration, I	431,912	I = (A*P*i%/12)*28.3168 liter/cf	Liters/year (appropriate unit conversions applied)
Dissolved Oxygen due to Precipitation, DO (Assumed from the Phase 2A area)	2.18	NA	mg/L, an average DO from four shallow wells in Phase 2A area (unamended), measured in Dec. 2016, was used. These four wells are 114-P2A-MW101S, 114-P2A-MW102S,114-P2A-MW103S, and 114-P2A-MW104S.
Flux of Dissolved Oxygen from Precipitation, Fop	0.9	Fop= (DO*I)/10^6 mg/kg	kg/year (appropriate unit conversions applied)
Oxygen Demand for FB-H to Reduce 1 gram of Oxygen, ODF	40.37	NA	gm FB-H/gm O_2, per stoichiometry (Attachment F)
Annual Oxidative Demand from Precipitation, OS	38.0	OS =Fop*ODF	kg FB-H/year
Oxidative Demand from Intermediate Zone	**Values**	**Calculations**	
Dissolved Oxygen in Groundwater, Doi	1.38	NA	mg/L, 114-MC-PZ203 (June-2016)
Upward Flux of Dissolved Oxygen from Intermediate Zone, Foi	0.09	Foi=(Q*Doi/10^6)*365 days/year	kg/year
Cr^{+6} Concentration in Intermediate Zone	**Values**	**Calculations**	
Average Concentration of Cr^{+6} in Groundwater, Cg	73	NA	mg/L, average of last four quarters of data from 114-MC-PZ103 & 114-MC-PZ203 (September 2015 through June 2016)
Cr^{+6} Concentration (Highest) in Soil in Intermediate Zone, Cs	501	NA	mg/kg, from 114-MC-PZ103 (40.5 - 41.0 ft)
Distribution coefficient, Kd	6.88	Cs/Cg	L/kg
Retardation Coefficient, Rf	44.96	Rf = 1+(ρb*(1.18655(gm/cc)/(ton/cy))/θT)*Kd	unitless (appropriate unit conversions applied)
Amended Backfill Soils	**Values**	**Calculations**	
FB-H Applied	776	NA	short tons, from field tracking logs
FB-H Applied	703,976	FB-H applied * 907.185 kg/ton	kg (appropriate unit conversions applied)
FB-H Amendment in the Soil Required to treat 1 gram of Cr^{+6} based on Stoichiometry, As	18.64	NA	gm FB-H/gm Cr^{+6}, per stoichiometry to reduce Cr^{+6} to Cr^{+3} (Attachment F)
Dosage of FB-H, X	0.028	NA	percentage by weight
Porosity of Dense Graded Aggregate (DGA), θ_{DGA}	0.26	NA	Reference: Capillary Break Design Report (GAG-036K) (AECOM, 2017)
Cr^{+6} concentration (pre-remediation) in the shallow zone	300	NA	mg/L, average concentrations from MW6A, PZ6 and PZ7
Amendment Depth	19.0	NA	ft
Mass of Cr^{+6} in open excavation reacting with FB-H	827	Area * Amendment depth * Cr^{+6} concentration * θ_{DGA} * (28.3168 L/ft^3) * (kg/10^6 mg)	kg (appropriate unit conversions applied)
Amount of FB-H exhausted by initial reaction with Cr^{+6}, FB-H Exhausted	15,422	(Mass of Cr^{+6} in excavation) * As	kg (appropriate unit conversions applied)
Remaining FB-H for long term reduction, FB-H Remaining	688,554	(FB-H Applied) - (FB-H exhausted)	kg (appropriate unit conversions applied)
FB-H Longevity	**Values**	**Calculations**	
Flux of Cr^{+6} per year from Intermediate Zone, F	0.11	F =((Cg/Rf)*365 days/year*Q)/10^6 mg/Kg	flux of Cr^{+6} (kg/year) (appropriate unit conversions applied)
Flux of Oxygen from Shallow and Intermediate Zone per year, Fo	1.04	Fo = Foi+Fop	flux of DO (kg/year)
Duration of FB-H Longevity Based on Combined effect of Stoichiometric Demand for Cr^{+6} Flux and Oxygen Flux, Tf	**15,710**	Tf = FB-H Remaining/(As*F + ODF*Fo)	years, longevity based on combined effect of oxygen flux and Cr^{+6} flux, excluding FB-H initially exhausted
Minimum quantity of FB-H required to sustain for 100 years, W_{100}	**5**	W_{100} = 100*((As*F*0.0011 Ton/Kg) + (ODF*Fo*0.0011 Ton/Kg))	tons (appropriate unit conversions applied)
Minimum thickness of FB-H amended soils to sustain for 100 years, d_{100}	**0.4**	d_{100} = W_{100}/(A*ρb*X/27 cf/cy)	ft of amended soil (appropriate unit conversions applied)
Minimum quantity of FB-H required to sustain for 30 years, W_{30}	**1.4**	W_{30} = W_{100}*0.3	tons
Minimum thickness of FB-H amended soils to sustain for 30 years, d_{30}	**0.13**	d_{30} = d_{100}*0.3	ft of amended soil

Notes:

* A negative hydraulic gradient indicates downward flow, and a positive value indicates upward flow.

Units from conversion factors are provided with them and the units for the individual parameter are under the Units/Description column.

CCPW - chromate chemical production waste	FB-H - FerroBlack®-H	L/kg - liters per kilogram	NA - Not Applicable	cc - cubic centimeter
cf - cubic feet	gm - grams	mg/Kg - milligram per kilogram	sf - square feet	cy - cubic yard
cf/day - cubic feet per day	gm/gm - gram per gram	mg/L - milligram per liter	ton/cy - ton per cubic yard	
ft - feet	kg - kilograms			

References:

AECOM, 2017. GAG-036K: Draft Capillary Break Design Report. May.
AECOM, 2016. GW-006D: Site-Wide Groundwater Summary Report (April 2015 through March 2016). June.
NJDEP, 2015. Discharge Approval and Monitoring Requirement Associated with Permit-By-Rule Discharge Authorization for PPG Industries (COPR). June.
Todd, D.K., 1980. Groundwater Hydrology [2^{nd} Edition]. Wiley, New York. 552 pp.

Estimation of FerroBlack®-H Longevity at Phase 1B (0.7% Amendment Area)

Data Input Cell
Variables for each phase
Data Output Cell

This FerroBlack®-H longevity estimate assumes the following:

The annual Cr^{+6} groundwater flux is constant and is based on the most current groundwater and soil concentration data;
The upward migration of Cr^{+6} in groundwater is subject to retardation, which is estimated from the apparent partitioning calculated as the ratio of the soil and aqueous chromium concentrations;
The Cr^{+6} and dissolved oxygen (DO) will be the primary oxidizing constituents of the reductants in FB-H; and
The vertical hydraulic conductivity is assumed to be 10% of the horizontal hydraulic conductivity.

Intermediate Zone Aquifer Properties	**Values**	**Calculations**	**Units/Description**
Horizontal Hydraulic Conductivity, Kh	0.86	NA	ft per day, used value from Phase 1A (nearest available)
Vertical Hydraulic Conductivity, Kv	0.09	NA	ft per day, assumed 10% of Kh (Reference: Groundwater Hydrology [2^{nd} ed.] by D. K. Todd. Wiley, New York, 1980. 552 pp.)
Average Vertical Hydraulic Gradient (I)*	0.0044	Groundwater flow is upward for small durations; conservatively, an upward gradient value was used	ft/ft, based on the transducer data from June 2016 to December 2016 (114-P1B-MW102I/102S).
Soil Bulk Density,ρb	1.62	NA	ton/cy, based on the values used in the approved groundwater pilot study Permit-By-Rule (PBR) application. Discharge Approval and Monitoring Requirement Associated with Permit-By-Rule Discharge Authorization for PPG Industries (COPR) (NJDEP, 2015)
Total Porosity, θT	30%	NA	percentage, same reference as mentioned above (NJDEP, 2015)
Area, A	50,695	NA	sf, Figure 3-4 of Site-Wide GW Summary Report - April 2015 through March 2016 (AECOM, 2016)
Upward Vertical Flow Rate, Qcf	19	Qcf=Kv*I*A	cf/day
Upward Vertical Flow Rate, Q	548	Q=Kv*I*A*28.3168 liter/cf	Liters/day (appropriate unit conversions applied)
Oxidative Demand from Precipitation in Shallow Zone	**Values**	**Calculations**	
Annual Precipitation, P	46.42	NA	inches/year, reference: www.usclimatedata.com
Annual Infiltration Rate, i%	20%	NA	based on HELP modeling (Attachment E).
Annual Total Infiltration, I	1,110,347	I = (A*P*i%/12)*28.3168 liter/cf	Liters/year (appropriate unit conversions applied)
Dissolved Oxygen due to Precipitation, DO (Assumed from the Phase 2A area)	2.18	NA	mg/L, an average DO from four shallow wells in Phase 2A area (unamended), measured in Dec. 2016, was used. These four wells are 114-P2A-MW101S, 114-P2A-MW102S,114-P2A-MW103S, and 114-P2A-MW104S.
Flux of Dissolved Oxygen from Precipitation, Fop	2	Fop= (DO*I)/10^6 mg/kg	kg/year (appropriate unit conversions applied)
Oxygen Demand for FB-H to Reduce 1 gram of Oxygen, ODF	40.37	NA	gm FB-H/gm O_2, per stoichiometry (Attachment F)
Annual Oxidative Demand from Precipitation, OS	97.7	OS =Fop*ODF	kg FB-H/year
Oxidative Demand from Intermediate Zone	**Values**	**Calculations**	
Dissolved Oxygen in Groundwater, Doi	1.06	NA	mg/L, Sep 2016 (114-P1B-MW102I)
Upward Flux of Dissolved Oxygen from Intermediate Zone, Foi	0.21	Foi=(Q*Doi/10^6)*365 days/year	kg/year
Cr^{+6} Concentration in Intermediate Zone	**Values**	**Calculations**	
Average Concentration of Cr^{+6} in Groundwater, Cg	206	NA	mg/L, average of last four quarters of data from 114-P1B-MW101I & 114-P1B-MW102I (September 2015 through June 2016)
Cr^{+6} Concentration (Highest) in Soil in Intermediate Zone, Cs	192	NA	mg/kg, from 114-P1B-MW102I (32.0 - 33.0 ft)
Distribution coefficient, Kd	0.93	Cs/Cg	L/kg
Retardation Coefficient, Rf	6.95	Rf = 1+(ρb*(1.18655(gm/cc)/(ton/cy))/θT)*Kd	unitless (appropriate unit conversions applied)
Amended Backfill Soils	**Values**	**Calculations**	
FB-H Applied	234	NA	short tons, from field tracking logs
FB-H Applied	212,281	FB-H applied * 907.185 kg/ton	kg (appropriate unit conversions applied)
FB-H Amendment in the Soil Required to treat 1 gram of Cr^{+6} based on Stoichiometry, As	18.64	NA	gm FB-H/gm Cr^{+6}, per stoichiometry to reduce Cr^{+6} to Cr^{+3} (Attachment F)
Dosage of FB-H, X	0.007	NA	percentage by weight
Porosity of Dense Graded Aggregate (DGA), θ_{DGA}	0.26	NA	Reference: Capillary Break Design Report (GAG-036K) (AECOM, 2017)
Cr^{+6} concentration (pre-remediation) in the shallow zone	200	NA	mg/L, average concentrations from MW12A, MW5A, PZ1, PZ2, PZ3, PZ4, PZ5
Amendment Depth	12.7	NA	ft
Mass of Cr^{+6} in open excavation reacting with FB-H	946	Area * Amendment depth * Cr^{+6} concentration * θ_{DGA} * (28.3168 L/ft^3) * (kg/10^6 mg)	kg (appropriate unit conversions applied)
Amount of FB-H exhausted by initial reaction with $Cr^{+6,}$, FB-H Exhausted	17,629	(Mass of Cr^{+6} in excavation) * As	kg (appropriate unit conversions applied)
Remaining FB-H for long term reduction, FB-H Remaining	194,652	(FB-H Applied) - (FB-H exhausted)	kg (appropriate unit conversions applied)
FB-H Longevity	**Values**	**Calculations**	
Flux of Cr^{+6} per year from Intermediate Zone, F	5.93	F =((Cg/Rf)*365 days/year*Q)/10^6 mg/Kg	flux of Cr^{+6} (kg/year) (appropriate unit conversions applied)
Flux of Oxygen from Shallow and Intermediate Zone per year, Fo	2.63	Fo = Foi+Fop	flux of DO (kg/year)
Duration of FB-H Longevity Based on Combined effect of Stoichiometric Demand for Cr^{+6} Flux and Oxygen Flux, Tf	**898**	Tf = FB-H Remaining/(As*F + ODF*Fo)	years, longevity based on combined effect of oxygen flux and Cr^{+6} flux, excluding FB-H initially exhausted
Minimum quantity of FB-H required to sustain for 100 years, W_{100}	**24**	W_{100} = 100*((As*F*0.0011 Ton/Kg) + (ODF*Fo*0.0011 Ton/Kg))	tons (appropriate unit conversions applied)
Minimum thickness of FB-H amended soils to sustain for 100 years, d_{100}	**1.1**	d_{100} = W_{100}/(A*ρb*X/27 cf/cy)	ft of amended soil (appropriate unit conversions applied)
Minimum quantity of FB-H required to sustain for 30 years, W_{30}	**7.2**	W_{30} = W_{100}*0.3	tons
Minimum thickness of FB-H amended soils to sustain for 30 years, d_{30}	**0.3**	d_{30} = d_{100}*0.3	ft of amended soil

Notes:
* A negative hydraulic gradient indicates downward flow, and a positive value indicates upward flow.
Units from conversion factors are provided with them and the units for the individual parameter are under the Units/Description column.

CCPW - chromate chemical production waste
cf - cubic feet
cf/day - cubic feet per day
ft - feet
FB-H - FerroBlack®-H
gm - grams
gm/gm - gram per gram
kg - kilograms
L/kg - liters per kilogram
mg/Kg - milligram per kilogram
mg/L - milligram per liter
NA - Not Applicable
sf - square feet
ton/cy - ton per cubic yard
cc - cubic centimeter
cy - cubic yard

References:

AECOM, 2017. GAG-036K: Draft Capillary Break Design Report. May.
AECOM, 2016. GW-006D: Site-Wide Groundwater Summary Report (April 2015 through March 2016). June.
NJDEP, 2015. Discharge Approval and Monitoring Requirement Associated with Permit-By-Rule Discharge Authorization for PPG Industries (COPR). June.
Todd, D.K., 1980. Groundwater Hydrology [2^{nd} Edition]. Wiley, New York. 552 pp.

Estimation of FerroBlack®-H Longevity at Phase 1C (2.8% Amendment Area)

This FerroBlack®-H longevity estimate assumes the following:

The annual Cr^{+6} groundwater flux is constant and is based on the most current groundwater and soil concentration data;
The upward migration of Cr^{+6} in groundwater is subject to retardation, which is estimated from the apparent partitioning calculated as the ratio of the soil and aqueous chromium concentrations;
The Cr^{+6} and dissolved oxygen (DO) will be the primary oxidizing constituents of the reductants in FB-H; and
The vertical hydraulic conductivity is assumed to be 10% of the horizontal hydraulic conductivity.

Data Input Cell
Variables for each phase
Data Output Cell

Intermediate Zone Aquifer Properties	**Values**	**Calculations**	**Units/Description**
Horizontal Hydraulic Conductivity, Kh	0.86	NA	ft per day, used value from Phase 1A (nearest available)
Vertical Hydraulic Conductivity, Kv	0.09	NA	ft per day, assumed 10% of Kh (Reference: Groundwater Hydrology [2nd ed.] by D. K. Todd. Wiley, New York, 1980. 552 pp.)
Average Vertical Hydraulic Gradient (I)*	-0.0085	Groundwater flow is downward	ft/ft, based on the transducer data from June 2016 to December 2016.
Soil Bulk Density,pb	1.62	NA	ton/cy, based on the values used in the approved groundwater pilot study Permit-By-Rule (PBR) application. Discharge Approval and Monitoring Requirement Associated with Permit-By-Rule Discharge Authorization for PPG Industries (COPR) (NJDEP, 2015)
Total Porosity, θT	30%	NA	percentage, same reference as mentioned above (NJDEP, 2015)
Area, A	40,656	NA	sf, Figure 3-4 of Site-Wide GW Summary Report - April 2015 through March 2016 (AECOM, 2016)
Upward Vertical Flow Rate, Qcf	0	Since flow is downward, assume zero flow upward	cf/day
Upward Vertical Flow Rate, Q	0	Q=Kv*I*A*28.3168 liter/cf	Liters/day (appropriate unit conversions applied)
Oxidative Demand from Precipitation in Shallow Zone	**Values**	**Calculations**	
Annual Precipitation, P	46.42	NA	inches/year, reference: www.usclimatedata.com
Annual Infiltration Rate, i%	20%	NA	based on HELP modeling (Attachment E).
Annual Total Infiltration, I	890,468	I = (A*P*i%/12)*28.3168 liter/cf	Liters/year (appropriate unit conversions applied)
Dissolved Oxygen due to Precipitation, DO (Assumed from the Phase 2A area)	2.18	NA	mg/L, an average DO from four shallow wells in Phase 2A area (unamended), measured in Dec. 2016, was used. These four wells are 114-P2A-MW101S, 114-P2A-MW102S,114-P2A-MW103S, and 114-P2A-MW104S.
Flux of Dissolved Oxygen from Precipitation, Fop	2	Fop= (DO*I)/10^6 mg/kg	kg/year (appropriate unit conversions applied)
Oxygen Demand for FB-H to Reduce 1 gram of Oxygen, ODF	40.37	NA	gm FB-H/gm O_2, per stoichiometry (Attachment F)
Annual Oxidative Demand from Precipitation, OS	78.4	OS =Fop*ODF	kg FB-H/year
Oxidative Demand from Intermediate Zone	**Values**	**Calculations**	
Dissolved Oxygen in Groundwater, Doi	0.63	NA	mg/L, June 2016 data, 114-P1C-MW101I
Upward Flux of Dissolved Oxygen from Intermediate Zone, Foi	0	Foi=(Q*Doi/10^6)*365 days/year	kg/year
Cr^{+6} Concentration in Intermediate Zone	**Values**	**Calculations**	
Average Concentration of Cr^{+6} in Groundwater, Cg	1.35	NA	mg/L, average of last four quarters of data from 114-P1C-PZ1 & 114-P1C-PZ2 (September 2015 through September 2016)
Cr^{+6} Concentration (Highest) in Soil in Intermediate Zone, Cs	18.2	NA	mg/kg, from 114-P1C-PZ1 (25.0 - 27.0 ft)
Distribution coefficient, Kd	13.47	Cs/Cg	L/kg
Retardation Coefficient, Rf	87.03	Rf = 1+(ρb*(1.18655(gm/cc)/(ton/cy))/θT)*Kd	unitless (appropriate unit conversions applied)
Cr^{+6} Concentration from Adjacent CCPW Area	**Values**	**Calculations**	
Depth of sheetpile in the saturated shallow zone, D	9	NA	ft, based on cross-sections and groundwater elevation maps (AECOM, 2016)
Width of entire sheetpile wall adjacent to the area, L	280	NA	ft
Width of each sheetpile unit,W	2.33	NA	ft
Opening between sheetpiles, Os	0.08	NA	ft
Area of opening, Ah	1	Ah= D*L	sq ft
Horizontal Hydraulic Gradient, Ih	0.01	ft/ft	ft/ft, based on observed hydraulic heads on either side of sheetpile (AECOM, 2016)
Horizontal Flow Rate from Leakage at one opening Sheetpile, Qs	0	Qs= Kh*Ah*Ih*28.3168 liter/cf	liters per day (appropriate unit conversions applied)
Number of openings at Sheetpile, Ns	60	L/W/2	assume opening for every 2 sheetpiles
Number of Interlocks of sheetpile, Ni	60	L/W/2	assume interlock for every 2 sheetpiles
Horizontal flow rate at each interlock, Qi	3	NA	liters per day, based on calculations proposed by Selleijer et.al, 1995
Total horizontal flow from CCPW area to the amended area, Ft	210	Ft=QI*Ns+Qi*Ni	liters per day
Concentration of Cr^{+6} in groundwater leaking from sheetpile adjacent to CCPW, Cadj	500	NA	mg/L, assumed
Amended Backfill Soils	**Values**	**Calculations**	
FB-H Applied	1,234	NA	short tons, from field tracking logs
FB-H Applied	1,119,238	FB-H applied * 907.185 kg/ton	kg (appropriate unit conversions applied)
FB-H Amendment in the Soil Required to treat 1 gram of Cr^{+6} based on Stoichiometry, As	18.64	NA	gm FB-H/gm Cr^{+6}, per stoichiometry to reduce Cr^{+6} to Cr^{+3} (Attachment F)
FB-H Dosage, X	0.028	NA	percentage by weight
Porosity of Dense Graded Aggregate (DGA), θ_{DGA}	0.26	NA	Reference: Capillary Break Design Report (GAG-036K) (AECOM, 2017)
Cr^{+6} concentration (pre-remediation) in the shallow zone	1,500	NA	mg/L, average concentrations from MW3A, 114-MW21A
Amendment Depth	14.5	NA	ft
Mass of Cr^{+6} in open excavation reacting with FB-H	6,515	Area * Amendment depth * Cr^{+6} concentration * θ_{DGA} * (28.3168 L/ft^3) * ($kg/10^6$ mg)	kg (appropriate unit conversions applied)
Amount of FB-H exhausted by initial reaction with Cr^{+6}, FB-H Exhausted	121,436	(Mass of Cr^{+6} in excavation) * As	kg (appropriate unit conversions applied)
Remaining FB-H for long term reduction, FB-H Remaining	997,802	(FB-H Applied) - (FB-H exhausted)	kg (appropriate unit conversions applied)
FB-H Longevity	**Values**	**Calculations**	
Flux of Cr^{+6} per year from Intermediate Zone, F	0.00	F =((Cg/Rf)*365 days/year*Q)/10^6 mg/Kg	flux of Cr^{+6} (kg/year) (appropriate unit conversions applied)
Flux of Cr^{+6} per year from adjacent CCPW area , Fadj	0.44	Fadj=((Cadj/Rf)*365 days/year*Ft)/10^6 mg/Kg	flux of Cr^{+6} from adjacent CCPW area (kg/year) (appropriate unit conversions applied)
Flux of Oxygen from Shallow and Intermediate Zone per year, Fo	1.94	Fo = Foi+Fop	flux of DO (kg/year)
Duration of FB-H Longevity Based on Combined effect of Stoichiometric Demand for Cr^{+6} Flux and Oxygen Flux, Tf	**11,524**	Tf = FB-H Remaining/(As*F+ As*Fadj + ODF*Fo)	years, longevity based on combined effect of oxygen flux and Cr^{+6} flux, excluding FB-H initially exhausted
Minimum quantity of FB-H required to sustain for 100 years, W_{100}	**9**	W_{100} = 100*((As*F*0.0011 Ton/Kg) + (ODF*Fo*0.0011 Ton/Kg))	tons (appropriate unit conversions applied)
Minimum thickness of FB-H amended soils to sustain for 100 years, d_{100}	**0.1**	d_{100} = W_{100}/(A*ρb*X/27 cf/cy)	ft of amended soil (appropriate unit conversions applied)
Minimum quantity of FB-H required to sustain for 30 years, W_{30}	**2.6**	W_{30} = W_{100}*0.3	tons
Minimum thickness of FB-H amended soils to sustain for 30 years, d_{30}	**0.04**	d_{30} = d_{100}*0.3	ft of amended soil

Notes:
* A negative hydraulic gradient indicates downward flow, and a positive value indicates upward flow.
Units from conversion factors are provided with them and the units for the individual parameter are under the Units/Description column.

CCPW - chromate chemical production waste
cf - cubic feet
cf/day - cubic feet per day
ft - feet
FB-H - FerroBlack®-H
gm - grams
gm/gm - gram per gram
kg - kilograms
L/kg - liters per kilogram
mg/Kg - milligram per kilogram
mg/L - milligram per liter
NA - Not Applicable
sf - square feet
ton/cy - ton per cubic yard
cc - cubic centimeter
cy - cubic yard

References:

AECOM, 2017. GAG-036K: Draft Capillary Break Design Report. May.
AECOM, 2016. GW-006D: Site-Wide Groundwater Summary Report (April 2015 through March 2016). June.
NJDEP, 2015. Discharge Approval and Monitoring Requirement Associated with Permit-By-Rule Discharge Authorization for PPG Industries (COPR). June.
Selleijer, J.B.; Cools, J. P. A. E.; Decker, J.; Post, W. J.; 1995. Hydraulic Resistance of Sheetpile Joints. Journal of Geotechnical Engineering. Vol 121, Issue 2. February 1995.
Todd, D.K., 1980. Groundwater Hydrology [2nd Edition]. Wiley, New York. 552 pp.

Estimation of FerroBlack®-H Longevity at Phase 2B-1 (2% Amendment Area)

This FerroBlack®-H longevity estimate assumes the following:

The annual Cr^{+6} groundwater flux is constant and is based on the most current groundwater and soil concentration data;
The upward migration of Cr^{+6} in groundwater is subject to retardation, which is estimated from the apparent partitioning calculated as the ratio of the soil and aqueous chromium concentrations;
The Cr^{+6} and dissolved oxygen (DO) will be the primary oxidizing constituents of the reductants in FB-H; and
The vertical hydraulic conductivity is assumed to be 10% of the horizontal hydraulic conductivity.

Data Input Cell
Variables for each phase
Data Output Cell

Intermediate Zone Aquifer Properties	**Values**	**Calculations**	**Units/Description**
Horizontal Hydraulic Conductivity, Kh	3.80	NA	ft per day, used Kh from 114-MW19B (P3C) - nearest phase with meadow mat
Vertical Hydraulic Conductivity, Kv	0.38	NA	ft per day, assumed 10% of Kh (Reference: Groundwater Hydrology [2nd ed.] by D. K. Todd. Wiley, New York, 1980. 552 pp.)
Average Vertical Hydraulic Gradient (I)*	0.0028	Groundwater flow is upward.	ft/ft, based on the transducer data from June 2016 to December 2016.
Soil Bulk Density,ρb	1.62	NA	ton/cy, based on the values used in the approved groundwater pilot study Permit-By-Rule (PBR) application. Discharge Approval and Monitoring Requirement Associated with Permit-By-Rule Discharge Authorization for PPG Industries (COPR) (NJDEP, 2015)
Total Porosity, θT	30%	NA	percentage, same reference as mentioned above (NJDEP, 2015)
Area, A	73,543	NA	sf, Figure 3-4 of Site-Wide GW Summary Report - April 2015 through March 2016 (AECOM, 2016)
Upward Vertical Flow Rate, Qcf	78	Qcf=Kv*I*A, no flow upward as the gradient is downward	cf/day
Upward Vertical Flow Rate, Q	2,198	Q=Kv*I*A*28.3168 liter/cf	Liters/day (appropriate unit conversions applied)
Oxidative Demand from Precipitation in Shallow Zone	**Values**	**Calculations**	
Annual Precipitation, P	46.42	NA	inches/year, reference: www.usclimatedata.com
Annual Infiltration Rate, i%	20%	NA	based on HELP modeling (Attachment E).
Annual Total Infiltration, I	1,610,776	I = (A*P*i%/12)*28.3168 liter/cf	Liters/year (appropriate unit conversions applied)
Dissolved Oxygen due to Precipitation, DO (Assumed from the Phase 2A area)	2.18	NA	mg/L, an average DO from four shallow wells in Phase 2A area (unamended), measured in Dec. 2016, was used. These four wells are 114-P2A-MW101S, 114-P2A-MW102S,114-P2A-MW103S, and 114-P2A-MW104S.
Flux of Dissolved Oxygen from Precipitation, Fop	4	Fop= (DO*I)/10^6 mg/kg	kg/year (appropriate unit conversions applied)
Oxygen Demand for FB-H to Reduce 1 gram of Oxygen, ODF	40.37	NA	gm FB-H/gm O_2, per stoichiometry (Attachment F)
Annual Oxidative Demand from Precipitation, OS	141.8	OS =Fop*ODF	kg FB-H/year
Oxidative Demand from Intermediate Zone	**Values**	**Calculations**	
Dissolved Oxygen in Groundwater, Doi	1.29	NA	mg/L, June 2016 data, 114-P2B1-MW101I
Upward Flux of Dissolved Oxygen from Intermediate Zone, Foi	1.03	Foi=(Q*Doi/10^6)*365 days/year	kg/year
Cr^{+6} Concentration in Intermediate Zone	**Values**	**Calculations**	
Average Concentration of Cr^{+6} in Groundwater, Cg	1,099	NA	mg/L, average of last four quarters of data from 114-P2B1-MW101I (September 2015 through June 2016)
Cr^{+6} Concentration (Highest) in Soil in Intermediate Zone, Cs	377	NA	mg/kg, from 114-P2B1-MW101I (32.0 - 32.5 ft)
Distribution coefficient, Kd	0.34	Cs/Cg	L/kg
Retardation Coefficient, Rf	3.19	Rf = 1+(ρb*(1.18655(gm/cc)/(ton/cy))/θT)*Kd	unitless (appropriate unit conversions applied)
Cr^{+6} Concentration from Adjacent CCPW Area	**Values**	**Calculations**	
Depth of sheetpile in saturated soils, D	45	NA	ft, based on cross-sections and groundwater elevation maps (AECOM, 2016)
Width of entire sheetpile wall adjacent to the area, L	186	NA	ft
Width of each sheetpile unit,W	2.33	NA	ft
Opening between sheetpiles, Os	0.08	NA	ft
Area of opening, Ah	4	Ah= D*L	sq ft
Horizontal Hydraulic Gradient, Ih	0.01	ft/ft	ft/ft, based on observed hydraulic heads on either side of sheetpile (AECOM, 2016)
Horizontal Flow Rate from Leakage at one opening Sheetpile, Qs	4	Qs= Kh*Ah*Ih*28.3168 liter/cf	liters per day (appropriate unit conversions applied)
Number of openings at Sheetpile, Ns	40	L/W/2	assume opening for every 2 sheetpiles
Number of Interlocks of sheetpile, Ni	40	L/W/2	assume interlock for every 2 sheetpiles
Horizontal flow rate at each interlock, Qi	3	NA	liters per day, based on calculations proposed by Selleijer et.al, 1995
Total horizontal flow from CCPW area to the amended area, Ft	293	Ft=Qi*Ns+Qi*Ni	liters per day
Concentration of Cr^{+6} in groundwater leaking from sheetpile adjacent to CCPW, Cadj	500	NA	mg/L, assumed
Amended Backfill Soils	**Values**	**Calculations**	
FB-H Applied	1,365	NA	short tons, from field tracking logs
FB-H Applied	1,238,055	FB-H applied * 907.185 kg/ton	kg (appropriate unit conversions applied)
FB-H Amendment in the Soil Required to treat 1 gram of Cr^{+6} based on Stoichiometry, As	18.64	NA	gm FB-H/gm Cr^{+6}, per stoichiometry to reduce Cr^{+6} to Cr^{+3} (Attachment F)
FB-H Dosage, X	0.02	NA	percentage by weight
Porosity of Dense Graded Aggregate (DGA), θ_{DGA}	0.26	NA	Reference: Capillary Break Design Report (GAG-036K) (AECOM, 2017)
Cr^{+6} concentration (pre-remediation) in the shallow zone	100	NA	mg/L, average concentrations from MW1S, 114-MW23A, MW11A
Amendment Depth	12.3	NA	ft
Mass of Cr^{+6} in open excavation reacting with FB-H	665	Area * Amendment depth * Cr^{+6} concentration * θ_{DGA} * (28.3168 L/ft^3) * (kg/10^6 mg)	kg (appropriate unit conversions applied)
Amount of FB-H exhausted by initial reaction with $Cr^{+6,}$, FB-H Exhausted	12,404	(Mass of Cr^{+6} in excavation) * As	kg (appropriate unit conversions applied)
Remaining FB-H for long term reduction, FB-H Remaining	1,225,651	(FB-H Applied) - (FB-H Exhausted)	kg (appropriate unit conversions applied)
FB-H Longevity	**Values**	**Calculations**	
Flux of Cr^{+6} per year from Intermediate Zone, F	276.27	F =((Cg/Rf)*365 days/year*Q)/10^6 mg/Kg	flux of Cr^{+6} from intermediate zone (kg/year) (appropriate unit conversions applied)
Flux of Cr^{+6} per year from adjacent CCPW area , Fadj	17	Fadj=((Cadj/Rf)*365 days/year*Ft)/10^6 mg/Kg	flux of Cr^{+6} from adjacent CCPW area (kg/year) (appropriate unit conversions applied)
Flux of Oxygen from Shallow and Intermediate Zone per year, Fo	4.55	Fo = Foi+Fop	flux of DO (kg/year)
Duration of FB-H Longevity Based on Combined effect of Stoichiometric Demand for Cr^{+6} Flux and Oxygen Flux, Tf	**217**	Tf = FB-H Remaining/(As*F+ As*Fadj + ODF*Fo)	years, longevity based on combined effect of oxygen flux and Cr^{+6} flux, excluding FB-H initially exhausted
Minimum quantity of FB-H required to sustain for 100 years, W_{100}	**588**	W_{100} = 100*((As*F*0.0011 Ton/Kg) + (ODF*Fo*0.0011 Ton/Kg))	tons (appropriate unit conversions applied)
Minimum thickness of FB-H amended soils to sustain for 100 years, d_{100}	**6.7**	d_{100} = W_{100}/(A*ρb*X/27 cf/cy)	ft of amended soil (appropriate unit conversions applied)
Minimum quantity of FB-H required to sustain for 30 years, W_{30}	**176.4**	W_{30} = W_{100}*0.3	tons
Minimum thickness of FB-H amended soils to sustain for 30 years, d_{30}	**2.0**	d_{30} = d_{100}*0.3	ft of amended soil

Notes:

* A negative hydraulic gradient indicates downward flow, and a positive value indicates upward flow.
Units from conversion factors are provided with them and the units for the individual parameter are under the Units/Description column.

CCPW - chromate chemical production waste
cf - cubic feet
cf/day - cubic feet per day
ft - feet
FB-H - FerroBlack®-H
gm - grams
gm/gm - gram per gram
kg - kilograms
L/kg - liters per kilogram
mg/Kg - milligram per kilogram
mg/L - milligram per liter
NA - Not Applicable
sf - square feet
ton/cy - ton per cubic yard
cc - cubic centimeter
cy - cubic yard

References:

AECOM, 2017. GAG-036K: Draft Capillary Break Design Report. May.
AECOM, 2016. GW-006D: Site-Wide Groundwater Summary Report (April 2015 through March 2016). June.
NJDEP, 2015. Discharge Approval and Monitoring Requirement Associated with Permit-By-Rule Discharge Authorization for PPG Industries (COPR). June.
Selleijer, J.B.; Cools, J. P. A. E.; Decker, J.; Post, W. J.; 1995. Hydraulic Resistance of Sheetpile Joints. Journal of Geotechnical Engineering. Vol 121, Issue 2. February 1995.
Todd, D.K., 1980. Groundwater Hydrology [2nd Edition]. Wiley, New York. 552 pp.

Attachment C
Longevity Evaluation for FerroBlack®-H Amended Backfill Soils
Garfield Avenue Group of Sites
PPG, Jersey City, New Jersey

AECOM

Estimation of FerroBlack®-H Longevity at Phase 2B-2 (0.7% Amendment Area)

This FerroBlack®-H longevity estimate assumes the following:

The annual Cr^{+6} groundwater flux is constant and is based on the most current groundwater and soil concentration data;

The upward migration of Cr^{+6} in groundwater is subject to retardation, which is estimated from the apparent partitioning calculated as the ratio of the soil and aqueous chromium concentrations;

The Cr^{+6} and dissolved oxygen (DO) will be the primary oxidizing constituents of the reductants in FB-H; and

The vertical hydraulic conductivity is assumed to be 10% of the horizontal hydraulic conductivity.

Data Input Cell
Variables for each phase
Data Output Cell

Intermediate Zone Aquifer Properties	**Values**	**Calculations**	**Units/Description**
Horizontal Hydraulic Conductivity, Kh	0.86	NA	ft per day, geomean of the Kh values from Phase 1A (nearest phase without meadow mat)
Vertical Hydraulic Conductivity, Kv	0.086	NA	ft per day, assumed 10% of Kh (Reference: Groundwater Hydrology [2^{nd} ed.] by D. K. Todd. Wiley, New York, 1980. 552 pp.)
Average Vertical Hydraulic Gradient (I)*	0.0028	Gradient data not available, assumed groundwater gradient is upward and used gradient value from Phase 2B-1 (nearest phase)	ft/ft, based on the transducer data from June 2016 to December 2016.
Soil Bulk Density,ρb	1.62	NA	ton/cy, based on the values used in the approved groundwater pilot study Permit-By-Rule (PBR) application. Discharge Approval and Monitoring Requirement Associated with Permit-By-Rule Discharge Authorization for PPG Industries (COPR) (NJDEP, 2015)
Total Porosity, θT	30%	NA	percentage, same reference as mentioned above (NJDEP, 2015)
Area, A	18,100	NA	sf, Figure 3-4 of Site-Wide GW Summary Report - April 2015 through March 2016 (AECOM, 2016)
Upward Vertical Flow Rate, Qcf	4	Qcf=Kv*I*A, no flow upward as the gradient is downward	cf/day
Upward Vertical Flow Rate, Q	122	Q=Kv*I*A*28.3168 liter/cf	Liters/day (appropriate unit conversions applied)
Oxidative Demand from Precipitation in Shallow Zone	**Values**	**Calculations**	
Annual Precipitation, P	46.42	NA	inches/year, reference: www.usclimatedata.com
Annual Infiltration Rate, i%	20%	NA	based on HELP modeling (Attachment E).
Annual Total Infiltration, I	396,435	I = (A*P*i%/12)*28.3168 liter/cf	Liters/year (appropriate unit conversions applied)
Dissolved Oxygen due to Precipitation, DO (Assumed from the Phase 2A area)	2.18	NA	mg/L, an average DO from four shallow wells in Phase 2A area (unamended), measured in Dec. 2016, was used. These four wells are 114-P2A-MW101S, 114-P2A-MW102S,114-P2A-MW103S, and 114-P2A-MW104S.
Flux of Dissolved Oxygen from Precipitation, Fop	1	Fop= (DO*I)/10^6 mg/kg	kg/year (appropriate unit conversions applied)
Oxygen Demand for FB-H to Reduce 1 gram of Oxygen, ODF	40.37	NA	gm FB-H/gm O_2, per stoichiometry (Attachment F)
Annual Oxidative Demand from Precipitation, OS	34.9	OS =Fop*ODF	kg FB-H/year
Oxidative Demand from Intermediate Zone	**Values**	**Calculations**	
Dissolved Oxygen in Groundwater, Doi	0.34	NA	mg/L, June 2016 data, 114-P2B2-MW101I
Upward Flux of Dissolved Oxygen from Intermediate Zone, Foi	0.02	Foi=(Q*Doi/10^6)*365 days/year	kg/year
Cr^{+6} Concentration in Intermediate Zone	**Values**	**Calculations**	
Average Concentration of Cr^{+6} in Groundwater, Cg	441	NA	mg/L, average of last four quarters of data from 114-P2B2-MW101I (September 2015 through June 2016)
Cr^{+6} Concentration (Highest) in Soil in Intermediate Zone, Cs	8.7	NA	mg/kg, from 114-P2B2-MW101I (27.0 - 27.5 ft)
Distribution coefficient, Kd	0.02	Cs/Cg	L/kg
Retardation Coefficient, Rf	1.13	Rf = 1+(ρb*(1.18655(gm/cc)/(ton/cy))/θT)*Kd	unitless (appropriate unit conversions applied)
Cr^{+6} Concentration from Adjacent CCPW Area	**Values**	**Calculations**	
Depth of sheetpile in saturated soils, D	36	NA	ft, based on cross-sections and groundwater elevation maps (AECOM, 2016) and sheetpile tip elevations
Width of entire sheetpile wall adjacent to the area, L	132	NA	ft
Width of each sheetpile unit,W	2.33	NA	ft
Opening between sheetpiles, Os	0.08	NA	ft
Area of opening, Ah	4,739	Ah= D*L	sq ft
Leakage Area	1%	NA	assumed
Horizontal Hydraulic Gradient, Ih	0.00	ft/ft	ft/ft, based on observed hydraulic heads on either side of sheetpile (AECOM, 2016)
Horizontal Flow Rate from Leakage at one opening Sheetpile, Qs	0.00	Qs= Kh*Ah*Ih*28.3168 liter/cf	liters per day (appropriate unit conversions applied)
Number of openings at Sheetpile, Ns	28	L/W/2	assume opening for every 2 sheetpiles
Number of Interlocks of sheetpile, Ni	28	L/W/2	assume interlock for every 2 sheetpiles
Horizontal flow rate at each interlock, Qi	0	NA	liters per day, based on calculations proposed by Selleijer et.al, 1995
Total horizontal flow from CCPW area to the amended area, Ft	0	Ft=Qi*Ns+Qi*Ni	liters per day
Concentration of Cr^{+6} in groundwater leaking from sheetpile adjacent to CCPW, Cadj	500	NA	mg/L, assumed
Amended Backfill Soils	**Values**	**Calculations**	
FB-H Applied	149	NA	short tons, from field tracking logs
FB-H Applied	135,143	FB-H applied * 907.185 kg/ton	kg (appropriate unit conversions applied)
FB-H Amendment in the Soil Required to treat 1 gram of Cr^{+6} based on Stoichiometry, As	18.64	NA	gm FB-H/gm Cr^{+6}, per stoichiometry to reduce Cr^{+6} to Cr^{+3} (Attachment F)
FB-H Dosage, X	0.007	NA	percentage by weight
Porosity of Dense Graded Aggregate (DGA), θ_{DGA}	0.26	NA	Reference: Capillary Break Design Report (GAG-036K) (AECOM, 2017)
Cr^{+6} concentration (pre-remediation) in the shallow zone	100	NA	mg/L, average concentrations from MW1S, 114-MW23A, MW11A
Amendment Depth	10.9	NA	ft
Mass of Cr^{+6} in open excavation reacting with FB-H	146	Area * Amendment depth * Cr^{+6} concentration * θ_{DGA} * (28.3168 L/ft^3) * (kg/10^6 mg)	kg (appropriate unit conversions applied)
Amount of FB-H exhausted by initial reaction with $Cr^{+6,}$, FB-H Exhausted	2,717	(Mass of Cr^{+6} in excavation) * As	kg (appropriate unit conversions applied)
Remaining FB-H for long term reduction, FB-H Remaining	132,426	(FB-H Applied) - (FB-H exhausted)	kg (appropriate unit conversions applied)
FB-H Longevity	**Values**	**Calculations**	
Flux of Cr^{+6} per year from Intermediate Zone, F	17.46	F =((Cg/Rf)*365 days/year*Q)/10^6 mg/Kg	flux of Cr^{+6} from intermediate zone (kg/year) (appropriate unit conversions applied)
Flux of Cr^{+6} per year from adjacent CCPW area , Fadj	0.00	Fadj=((Cadj/Rf)*365 days/year*Ft)/10^6 mg/Kg	flux of Cr^{+6} from adjacent CCPW area (kg/year) (appropriate unit conversions applied)
Flux of Oxygen from Shallow and Intermediate Zone per year, Fo	0.88	Fo = Foi+Fop	flux of DO (kg/year)
Duration of FB-H Longevity Based on Combined effect of Stoichiometric Demand for Cr^{+6} Flux and Oxygen Flux, Tf	**367**	Tf = FB-H Remaining/(As*F+ As*Fadj + ODF*Fo)	years, longevity based on combined effect of oxygen flux and Cr^{+6} flux, excluding FB-H initially exhausted
Minimum quantity of FB-H required to sustain for 100 years, W_{100}	**39.8**	W_{100} = 100*((As*F*0.0011 Ton/Kg) + (ODF*Fo*0.0011 Ton/Kg))	tons (appropriate unit conversions applied)
Minimum thickness of FB-H amended soils to sustain for 100 years, d_{100}	**5.2**	d_{100} = W_{100}/(A*ρb*X/27 cf/cy)	ft of amended soil (appropriate unit conversions applied)
Minimum quantity of FB-H required to sustain for 30 years, W_{30}	**11.9**	W_{30} = W_{100}*0.3	tons
Minimum thickness of FB-H amended soils to sustain for 30 years, d_{30}	**1.6**	d_{30} = d_{100}*0.3	ft of amended soil

Notes:

* A negative hydraulic gradient indicates downward flow, and a positive value indicates upward flow.

Units from conversion factors are provided with them and the units for the individual parameter are under the Units/Description column.

CCPW - chromate chemical production waste
cf - cubic feet
cf/day - cubic feet per day
ft - feet
FB-H - FerroBlack®-H
gm - grams
gm/gm - gram per gram
kg - kilograms
L/kg - liters per kilogram
mg/Kg - milligram per kilogram
mg/L - milligram per liter
NA - Not Applicable
sf - square feet
ton/cy - ton per cubic yard
cc - cubic centimeter
cy - cubic yard

References:

AECOM, 2017. GAG-036K: Draft Capillary Break Design Report. May.

AECOM, 2016. GW-006D: Site-Wide Groundwater Summary Report (April 2015 through March 2016). June.

NJDEP, 2015. Discharge Approval and Monitoring Requirement Associated with Permit-By-Rule Discharge Authorization for PPG Industries (COPR). June.

Selleijer, J.B.; Cools, J. P. A. E.; Decker, J.; Post, W. J.; 1995. Hydraulic Resistance of Sheetpile Joints. Journal of Geotechnical Engineering. Vol 121, Issue 2. February 1995.

Todd, D.K., 1980. Groundwater Hydrology [2^{nd} Edition]. Wiley, New York. 552 pp.

Estimation of FerroBlack®-H Longevity at Phase 2B-3 (0.7% Amendment Area)

This FerroBlack®-H longevity estimate assumes the following:

The annual Cr^{+6} groundwater flux is constant and is based on the most current groundwater and soil concentration data;
The upward migration of Cr^{+6} in groundwater is subject to retardation, which is estimated from the apparent partitioning calculated as the ratio of the soil and aqueous chromium concentrations;
The Cr^{+6} and dissolved oxygen (DO) will be the primary oxidizing constituents of the reductants in FB-H; and
The vertical hydraulic conductivity is assumed to be 10% of the horizontal hydraulic conductivity.

Data Input Cell
Variables for each phase
Data Output Cell

Intermediate Zone Aquifer Properties	**Values**	**Calculations**	**Units/Description**
Horizontal Hydraulic Conductivity, Kh	3.80	NA	ft per day, used Kh from 114-MW19B (P3C) - nearest phase with meadow mat
Vertical Hydraulic Conductivity, Kv	0.38	NA	ft per day, assumed 10% of Kh (Reference: Groundwater Hydrology [2nd ed.] by D. K. Todd. Wiley, New York, 1980. 552 pp.)
Average Vertical Hydraulic Gradient (I)*	0.0019	Groundwater flow is upward for a small duration; conservatively, upward gradient value is used.	ft/ft, based on the transducer data from June 2016 to December 2016.
Soil Bulk Density,ρb	1.62	NA	ton/cy, based on the values used in the approved groundwater pilot study Permit-By-Rule (PBR) application. Discharge Approval and Monitoring Requirement Associated with Permit-By-Rule Discharge Authorization for PPG Industries (COPR) (NJDEP, 2015)
Total Porosity, θT	30%	NA	percentage, same reference as mentioned above (NJDEP, 2015)
Area, A	14,269	NA	sf, Figure 3-4 of Site-Wide GW Summary Report - April 2015 through March 2016 (AECOM, 2016)
Upward Vertical Flow Rate, Qcf	10	Qcf=Kv*I*A, no flow upward as the gradient is downward	cf/day
Upward Vertical Flow Rate, Q	292	Q=Kv*I*A*28.3168 liter/cf	Liters/day (appropriate unit conversions applied)
Oxidative Demand from Precipitation in Shallow Zone	**Values**	**Calculations**	
Annual Precipitation, P	46.42	NA	inches/year, reference: www.usclimatedata.com
Annual Infiltration Rate, i%	20%	NA	based on HELP modeling (Attachment E).
Annual Total Infiltration, I	312,527	I = (A*P*i%/12)*28.3168 liter/cf	Liters/year (appropriate unit conversions applied)
Dissolved Oxygen due to Precipitation, DO (Assumed from the Phase 2A area)	2.18	NA	mg/L, an average DO from four shallow wells in Phase 2A area (unamended), measured in Dec. 2016, was used. These four wells are 114-P2A-MW101S, 114-P2A-MW102S,114-P2A-MW103S, and 114-P2A-MW104S.
Flux of Dissolved Oxygen from Precipitation, Fop	1	Fop= (DO*I)/10^6 mg/kg	kg/year (appropriate unit conversions applied)
Oxygen Demand for FB-H to Reduce 1 gram of Oxygen, ODF	40.37	NA	gm FB-H/gm O_2, per stoichiometry (Attachment F)
Annual Oxidative Demand from Precipitation, OS	27.5	OS =Fop*ODF	kg FB-H/year
Oxidative Demand from Intermediate Zone	**Values**	**Calculations**	
Dissolved Oxygen in Groundwater, Doi	0.89	NA	mg/L, June 2016 data, 114-P2B3-MW101I
Upward Flux of Dissolved Oxygen from Intermediate Zone, Foi	0.09	Foi=(Q*Doi/10^6)*365 days/year	kg/year (appropriate unit conversions applied)
Cr^{+6} Concentration in Intermediate Zone	**Values**	**Calculations**	
Average Concentration of Cr^{+6} in Groundwater, Cg	328	NA	mg/L, average of last four quarters of data from 114-P2B3-MW101I (September 2015 through June 2016)
Cr^{+6} Concentration (Highest) in Soil in Intermediate Zone, Cs	165	NA	mg/kg, from 114-P2B3-MW101I (33.5 - 34.0 ft)
Distribution coefficient, Kd	0.50	Cs/Cg	L/kg
Retardation Coefficient, Rf	4.22	Rf = 1+(ρb*(1.18655(gm/cc)/(ton/cy))/θT)*Kd	unitless (appropriate unit conversions applied)
Cr^{+6} Concentration from Adjacent CCPW Area	**Values**	**Calculations**	
Depth of sheetpile in saturated soils, D	56	NA	ft, based on cross-sections and groundwater elevation maps (AECOM, 2016)
Width of entire sheetpile wall adjacent to the area, L	240	NA	ft
Width of each sheetpile unit,W	2.33	NA	ft
Opening between sheetpiles, Os	0.08	NA	ft
Area of opening, Ah	5	Ah= D*L	sq ft
Horizontal Hydraulic Gradient, Ih	0.00	ft/ft	ft/ft, based on observed hydraulic heads on either side of sheetpile (AECOM, 2016)
Horizontal Flow Rate from Leakage at one opening Sheetpile, Qs	0	Qs= Kh*Ah*Ih*28.3168 liter/cf	liters per day (appropriate unit conversions applied)
Number of openings at Sheetpile, Ns	52	L/W/2	assume opening for every 2 sheetpiles
Number of Interlocks of sheetpile, Ni	52	L/W/2	assume interlock for every 2 sheetpiles
Horizontal flow rate at each interlock, Qi	0	NA	liters per day, based on calculations proposed by Selleijer et.al, 1995
Total horizontal flow from CCPW area to the amended area, Ft	0	Ft=Qi*Ns+Qi*Ni	liters per day
Concentration of Cr^{+6} in groundwater leaking from sheetpile adjacent to CCPW, Cadj	500	NA	mg/L, assumed
Amended Backfill Soils	**Values**	**Calculations**	
FB-H Applied	148	NA	short tons, from field tracking logs
FB-H Applied	134,236	FB-H applied * 907.185 kg/ton	kg (appropriate unit conversions applied)
FB-H Amendment in the Soil Required to treat 1 gram of Cr^{+6} based on Stoichiometry, As	18.64	NA	gm FB-H/gm Cr^{+6}, per stoichiometry to reduce Cr^{+6} to Cr^{+3} (Attachment F)
FB-H Dosage, X	0.007	NA	percentage by weight
Porosity of Dense Graded Aggregate (DGA), θ_{DGA}	0.26	NA	Reference: Capillary Break Design Report (GAG-036K) (AECOM, 2017)
Cr^{+6} concentration (pre-remediation) in the shallow zone	100	NA	mg/L, average concentrations from MW2S, MW7A, MW10A
Amendment Depth	13.2	NA	ft
Mass of Cr^{+6} in open excavation reacting with FB-H	139	Area * Amendment depth * Cr^{+6} concentration * θ_{DGA} * (28.3168 L/ft^3) * (kg/10^6 mg)	kg (appropriate unit conversions applied)
Amount of FB-H exhausted by initial reaction with Cr^{+6}, FB-H Exhausted	2,593	(Mass of Cr^{+6} in excavation) * As	kg (appropriate unit conversions applied)
Remaining FB-H for long term reduction, FB-H Remaining	131,643	(FB-H Applied) - (FB-H exhausted)	kg (appropriate unit conversions applied)
FB-H Longevity	**Values**	**Calculations**	
Flux of Cr^{+6} per year from Intermediate Zone, F	8.29	F =((Cg/Rf)*365 days/year*Q)/10^6 mg/Kg	flux of Cr^{+6} from intermediate zone (kg/year) (appropriate unit conversions applied)
Flux of Cr^{+6} per year from adjacent CCPW area , Fadj	0.0	Fadj=((Cadj/Rf)*365 days/year*Ft)/10^6 mg/Kg	flux of Cr^{+6} from adjacent CCPW area (kg/year) (appropriate unit conversions applied)
Flux of Oxygen from Shallow and Intermediate Zone per year, Fo	0.78	Fo = Foi+Fop	flux of DO (kg/year)
Duration of FB-H Longevity Based on Combined effect of Stoichiometric Demand for Cr^{+6} Flux and Oxygen Flux, Tf	**708**	Tf = FB-H Remaining/(As*F+ As*Fadj + ODF*Fo)	years, longevity based on combined effect of oxygen flux and Cr^{+6} flux, excluding FB-H initially exhausted
Minimum quantity of FB-H required to sustain for 100 years, W_{100}	**20.5**	W_{100} = 100*((As*F*0.0011 Ton/Kg) + (ODF*Fo*0.0011 Ton/Kg))	tons (appropriate unit conversions applied)
Minimum thickness of FB-H amended soils to sustain for 100 years, d_{100}	**3.4**	d_{100} = W_{100}/(A*ρb*X/27 cf/cy)	ft of amended soil (appropriate unit conversions applied)
Minimum quantity of FB-H required to sustain for 30 years, W_{30}	**6.1**	W_{30} = W_{100}*0.3	tons
Minimum thickness of FB-H amended soils to sustain for 30 years, d_{30}	**1.0**	d_{30} = d_{100}*0.3	ft of amended soil

Notes:
* A negative hydraulic gradient indicates downward flow, and a positive value indicates upward flow.
Units from conversion factors are provided with them and the units for the individual parameter are under the Units/Description column.

CCPW - chromate chemical production waste
cf - cubic feet
cf/day - cubic feet per day
ft - feet
FB-H - FerroBlack®-H
gm - grams
gm/gm - gram per gram
kg - kilograms
L/kg - liters per kilogram
mg/Kg - milligram per kilogram
mg/L - milligram per liter
NA - Not Applicable
sf - square feet
ton/cy - ton per cubic yard
cc - cubic centimeter
cy - cubic yard

References:

AECOM, 2017. GAG-036K: Draft Capillary Break Design Report. May.
AECOM, 2016. GW-006D: Site-Wide Groundwater Summary Report (April 2015 through March 2016). June.
NJDEP, 2015. Discharge Approval and Monitoring Requirement Associated with Permit-By-Rule Discharge Authorization for PPG Industries (COPR). June.
Selleijer, J.B.; Cools, J. P. A. E.; Decker, J.; Post, W. J.; 1995. Hydraulic Resistance of Sheetpile Joints. Journal of Geotechnical Engineering. Vol 121, Issue 2. February 1995.
Todd, D.K., 1980. Groundwater Hydrology [2nd Edition]. Wiley, New York. 552 pp.

Estimation of FerroBlack®-H Longevity at Phase 2B-4 (0.7% Amendment Area)

Data Input Cell
Variables for each phase
Data Output Cell

This FerroBlack®-H longevity estimate assumes the following:

The longevity estimates is considered as average values, since fluxes of hexavalent chromium (Cr^{+6}) may not be homogeneous;
The upward migration of Cr^{+6} in groundwater is subject to retardation, which is estimated from the apparent partitioning calculated as the ratio of the soil and aqueous chromium concentrations;
The upward migration of Cr^{+6} in groundwater is subject to retardation and which is estimated from the apparent partitioning calculated as the ratio of the soil and aqueous chromium concentrations;
The Cr^{+6} and dissolved oxygen (DO) will be the primary oxidizing constituents of the reductants in FB-H; and
The vertical hydraulic conductivity is assumed to be 10% of the horizontal hydraulic conductivity.

Intermediate Zone Aquifer Properties	**Values**	**Calculations**	**Units/Description**
Horizontal Hydraulic Conductivity, Kh	3.80	NA	ft per day, used Kh from 114-MW19B (P3C) - nearest phase with meadow mat
Vertical Hydraulic Conductivity, Kv	0.38	NA	ft per day, assumed 10% of Kh (Reference: Groundwater Hydrology [2nd ed.] by D. K. Todd. Wiley, New York, 1980. 552 pp.)
Average Vertical Hydraulic Gradient (I)*	0.0022	Groundwater flow is upward for a short duration; conservatively, the upward gradient value is used	ft/ft, based on the transducer data from June 2016 to December 2016.
Soil Bulk Density,ρb	1.62	NA	ton/cy, based on the values used in the approved groundwater pilot study Permit-By-Rule (PBR) application. Discharge Approval and Monitoring Requirement Associated with Permit-By-Rule Discharge Authorization for PPG Industries (COPR) (NJDEP, 2015)
Total Porosity, θT	30%	NA	percentage, same reference as mentioned above (NJDEP, 2015)
Area, A	42,253	NA	sf, Figure 3-4 of Site-Wide GW Summary Report - April 2015 through March 2016 (AECOM, 2016)
Upward Vertical Flow Rate, Qcf	36	Qcf=Kv*I*A, no flow upward as the gradient is downward	cf/day
Upward Vertical Flow Rate, Q	1,020	Q=Kv*I*A*28.3168 liter/cf	Liters/day (appropriate unit conversions applied)
Oxidative Demand from Precipitation in Shallow Zone	**Values**	**Calculations**	
Annual Precipitation, P	46.42	NA	inches/year, reference: www.usclimatedata.com
Annual Infiltration Rate, i%	20%	NA	based on HELP modeling (Attachment E).
Annual Total Infiltration, I	925,446	I = (A*P*i%/12)*28.3168 liter/cf	Liters/year (appropriate unit conversions applied)
Dissolved Oxygen due to Precipitation, DO (Assumed from the Phase 2A area)	2.18	NA	mg/L, an average DO from four shallow wells in Phase 2A area (unamended), measured in Dec. 2016, was used. These four wells are 114-P2A-MW101S, 114-P2A-MW102S,114-P2A-MW103S, and 114-P2A-MW104S.
Flux of Dissolved Oxygen from Precipitation, Fop	2	Fop= (DO*I)/10^6 mg/kg	kg/year (appropriate unit conversions applied)
Oxygen Demand for FB-H to Reduce 1 gram of Oxygen, ODF	40.37	NA	gm FB-H/gm O_2, per stoichiometry (Attachment E)
Annual Oxidative Demand from Precipitation, OS	81.4	OS =Fop*ODF	kg FB-H/year
Oxidative Demand from Intermediate Zone	**Values**	**Calculations**	
Dissolved Oxygen in Groundwater, Doi	1.39	NA	mg/L, June 2016 data, 114-P2B4-MW101I
Upward Flux of Dissolved Oxygen from Intermediate Zone, Foi	0.52	Foi=(Q*Doi/10^6)*365 days/year	kg/year (appropriate unit conversions applied)
Cr^{+6} Concentration in Intermediate Zone	**Values**	**Calculations**	
Average Concentration of Cr^{+6} in Groundwater, Cg	298	NA	mg/L, average of last four quarters of data from 114-P2B4-MW101I & 114-P2B4-MW102I (September 2015 through June 2016)
Cr^{+6} Concentration (Highest) in Soil in Intermediate Zone, Cs	287	NA	mg/kg, from 114-P2B4-MW101I (47.5 - 48.0 ft)
Distribution coefficient, Kd	0.96	Cs/Cg	L/kg
Retardation Coefficient, Rf	7.14	Rf = 1+(ρb*(1.18655(gm/cc)/(ton/cy))/θT)*Kd	unitless (appropriate unit conversions applied)
Cr^{+6} Concentration from Adjacent CCPW Area	**Values**	**Calculations**	
Depth of FerroBlack Amended Area sheetpile, D	56	NA	ft, based on cross-sections and groundwater elevation maps (AECOM, 2016)
Width of entire sheetpile wall adjacent to the area, L	180	NA	ft
Width of each sheetpile unit,W	2.33	NA	ft
Opening between sheetpiles, Os	0.08	NA	ft
Area of opening, Ah	5	Ah= D*L	sq ft
Horizontal Hydraulic Gradient, Ih	0.00	ft/ft	ft/ft, based on observed hydraulic heads on either side of sheetpile (AECOM, 2016)
Horizontal Flow Rate from Leakage at one opening Sheetpile, Qs	0	Qs= Kh*Ah*Ih*28.3168 liter/cf	liters per day (appropriate unit conversions applied)
Number of openings at Sheetpile, Ns	39	L/W/2	assume opening for every 2 sheetpiles
Number of Interlocks of sheetpile, Ni	39	L/W/2	assume interlock for every 2 sheetpiles
Horizontal flow rate at each interlock, Qi	0	NA	liters per day, based on calculations proposed by Selleijer et.al, 1995
Total horizontal flow from CCPW area to the amended area, Ft	0	Ft=Qi*Ns+Qi*Ni	liters per day
Concentration of Cr^{+6} in groundwater leaking from sheetpile adjacent to CCPW, Cadj	500	NA	mg/L, assumed
Amended Backfill Soils	**Values**	**Calculations**	
FB-H Applied	326	NA	short tons, from field tracking logs
FB-H Applied	295,682	FB-H applied * 907.185 kg/ton	kg (appropriate unit conversions applied)
FB-H Amendment in the Soil Required to treat 1 gram of Cr^{+6} based on Stoichiometry, As	18.64	NA	gm FB-H/gm Cr^{+6}, per stoichiometry to reduce Cr^{+6} to Cr^{+3} (Attachment E)
FB-H Dosage, X	0.007	NA	percentage by weight
Porosity of Dense Graded Aggregate (DGA), θ_{DGA}	0.26	NA	Reference: Capillary Break Design Report (GAG-036K) (AECOM, 2017)
Cr^{+6} concentration (pre-remediation) in the shallow zone	300	NA	mg/L, average concentrations from MW8A, MW13A
Amendment Depth	13.4	NA	ft
Mass of Cr^{+6} in open excavation reacting with FB-H	1,252	Area * Amendment depth * Cr^{+6} concentration * θ_{DGA} * (28.3168 L/ft^3) * (kg/10^6 mg)	kg (appropriate unit conversions applied)
Amount of FB-H exhausted by initial reaction with Cr^{+6}, FB-H Exhausted	23,345	(Mass of Cr^{+6} in excavation) * As	kg (appropriate unit conversions applied)
Remaining FB-H for long term reduction, FB-H Remaining	272,337	(FB-H Applied) - (FB-H exhausted)	kg (appropriate unit conversions applied)
FB-H Longevity	**Values**	**Calculations**	
Flux of Cr^{+6} per year from Intermediate Zone, F	15.56	F =((Cg/Rf)*365 days/year*Q)/10^6 mg/Kg	flux of Cr^{+6} from intermediate zone (kg/year) (appropriate unit conversions applied)
Flux of Cr^{+6} per year from adjacent CCPW area , Fadj	0	Fadj=((Cadj/Rf)*365 days/year*Ft)/10^6 mg/Kg	flux of Cr^{+6} from adjacent CCPW area (kg/year) (appropriate unit conversions applied)
Flux of Oxygen from Shallow and Intermediate Zone per year, Fo	2.54	Fo = Foi+Fop	flux of DO (kg/year)
Duration of FB-H Longevity Based on Combined effect of Stoichiometric Demand for Cr^{+6} Flux and Oxygen Flux, Tf	**694**	Tf = FB-H Remaining/(As*F+ As*Fadj + ODF*Fo)	years, longevity based on combined effect of oxygen flux and Cr^{+6} flux, excluding FB-H initially exhausted
Minimum quantity of FB-H required to sustain for 100 years, W_{100}	**43.3**	W_{100} = 100*((As*F*0.0011 Ton/Kg) + (ODF*Fo*0.0011 Ton/Kg))	tons (appropriate unit conversions applied)
Minimum thickness of FB-H amended soils to sustain for 100 years, d_{100}	**2.4**	d_{100} = W_{100}/(A*ρb*X/27 cf/cy)	ft of amended soil (appropriate unit conversions applied)
Minimum quantity of FB-H required to sustain for 30 years, W_{30}	**13.0**	W_{30} = W_{100}*0.3	tons
Minimum thickness of FB-H amended soils to sustain for 30 years, d_{30}	**0.7**	d_{30} = d_{100}*0.3	ft of amended soil

Notes:
* A negative hydraulic gradient indicates downward flow, and a positive value indicates upward flow.
Units from conversion factors are provided with them and the units for the individual parameter are under the Units/Description column.

CCPW - chromate chemical production waste
cf - cubic feet
cf/day - cubic feet per day
ft - feet
FB-H - FerroBlack®-H
gm - grams
gm/gm - gram per gram
kg - kilograms
L/kg - liters per kilogram
mg/Kg - milligram per kilogram
mg/L - milligram per liter
NA - Not Applicable
sf - square feet
ton/cy - ton per cubic yard
cc - cubic centimeter
cy - cubic yard

References:

AECOM, 2017. GAG-036K: Draft Capillary Break Design Report. May.
AECOM, 2016. GW-006D: Site-Wide Groundwater Summary Report (April 2015 through March 2016). June.
NJDEP, 2015. Discharge Approval and Monitoring Requirement Associated with Permit-By-Rule Discharge Authorization for PPG Industries (COPR). June.
Selleijer, J.B.; Cools, J. P. A. E.; Decker, J.; Post, W. J.; 1995. Hydraulic Resistance of Sheetpile Joints. Journal of Geotechnical Engineering. Vol 121, Issue 2. February 1995.
Todd, D.K., 1980. Groundwater Hydrology [2nd Edition]. Wiley, New York. 552 pp.

Estimation of FerroBlack®-H Longevity at Phase 3A (0.7% Amendment Area)

This FerroBlack®-H longevity estimate assumes the following:

The annual Cr^{+6} groundwater flux is constant and is based on the most current groundwater and soil concentration data;
The upward migration of Cr^{+6} in groundwater is subject to retardation, which is estimated from the apparent partitioning calculated as the ratio of the soil and aqueous chromium concentrations;
The Cr^{+6} and dissolved oxygen (DO) will be the primary oxidizing constituents of the reductants in FB-H; and
The vertical hydraulic conductivity is assumed to be 10% of the horizontal hydraulic conductivity.

Data Input Cell
Variables for each phase
Data Output Cell

Intermediate Zone Aquifer Properties	**Values**	**Calculations**	**Units/Description**
Horizontal Hydraulic Conductivity, Kh	3.80	NA	ft per day, used Kh from 114-MW19B (P3C) - nearest phase with meadow mat
Vertical Hydraulic Conductivity, Kv	0.38	NA	ft per day, assumed 10% of Kh (Reference: Groundwater Hydrology [2nd ed.] by D. K. Todd. Wiley, New York, 1980. 552 pp.)
Average Vertical Hydraulic Gradient (I)*	-0.0737	Groundwater flow is downward.	ft/ft, based on the transducer data from June 2016 to December 2016. An average gradient from 132-P3A-MW102I and 132-P3A-MW104I was used.
Soil Bulk Density,ρb	1.62	NA	ton/cy, based on the values used in the approved groundwater pilot study Permit-By-Rule (PBR) application. Discharge Approval and Monitoring Requirement Associated with Permit-By-Rule Discharge Authorization for PPG Industries (COPR) (NJDEP, 2015)
Total Porosity, θT	30%	NA	percentage, same reference as mentioned above (NJDEP, 2015)
Area, A	15,300	NA	sf, Figure 3-4 of Site-Wide GW Summary Report - April 2015 through March 2016 (AECOM, 2016)
Upward Vertical Flow Rate, Qcf	0	Qcf=Kv*I*A, no flow upward as the gradient is downward	cf/day
Upward Vertical Flow Rate, Q	0	Q=Kv*I*A*28.3168 liter/cf	Liters/day (appropriate unit conversions applied)
Oxidative Demand from Precipitation in Shallow Zone	**Values**	**Calculations**	
Annual Precipitation, P	46.42	NA	inches/year, reference: www.usclimatedata.com
Annual Infiltration Rate, i%	20%	NA	based on HELP modeling (Attachment E).
Annual Total Infiltration, I	335,108	I = (A*P*i%/12)*28.3168 liter/cf	Liters/year (appropriate unit conversions applied)
Dissolved Oxygen due to Precipitation, DO (Assumed from the Phase 2A area)	2.18	NA	mg/L, an average DO from four shallow wells in Phase 2A area (unamended), measured in Dec. 2016, was used. These four wells are 114-P2A-MW101S, 114-P2A-MW102S,114-P2A-MW103S, and 114-P2A-MW104S.
Flux of Dissolved Oxygen from Precipitation, Fop	1	Fop= (DO*I)/10^6 mg/kg	kg/year (appropriate unit conversions applied)
Oxygen Demand for FB-H to Reduce 1 gram of Oxygen, ODF	40.37	NA	gm FB-H/gm O_2, per stoichiometry (Attachment F)
Annual Oxidative Demand from Precipitation, OS	29.5	OS =Fop*ODF	kg FB-H/year
Oxidative Demand from Intermediate Zone	**Values**	**Calculations**	
Dissolved Oxygen in Groundwater, Doi	0.39	NA	mg/L, June 2016 (143-P3A-MW101I)
Upward Flux of Dissolved Oxygen from Intermediate Zone, Foi	0.00	Foi=(Q*Doi/10^6)*365 days/year	kg/year
Cr^{+6} Concentration in Intermediate Zone	**Values**	**Calculations**	
Average Concentration of Cr^{+6} in Groundwater, Cg	21	NA	mg/L, average of last four quarters of data from 132-P3A-MW103I & 143-P3A-MW101I (September 2015 through June 2016)
Cr^{+6} Concentration (Highest) in Soil in Intermediate Zone, Cs	97	NA	mg/kg, from 143-P3A-MW101I (25.0 - 25.5 ft)
Distribution coefficient, Kd	4.63	Cs/Cg	L/kg
Retardation Coefficient, Rf	30.58	Rf = 1+(ρb*(1.18655(gm/cc)/(ton/cy))/θT)*Kd	unitless (appropriate unit conversions applied)
Cr^{+6} Concentration from Adjacent CCPW Area	**Values**	**Calculations**	
Depth of sheetpile in the saturated shallow zone, D	52	NA	ft, based on cross-sections and groundwater elevation maps (AECOM, 2016)
Width of entire sheetpile wall adjacent to the area, L	400	NA	ft
Width of each sheetpile unit,W	2.33	NA	ft
Opening between sheetpiles, Os	0.08	NA	ft
Area of opening, Ah	4	Ah= D*L	sq ft
Leakage Area	1%	NA	assumed
Horizontal Hydraulic Gradient, Ih	0.00	ft/ft	ft/ft, based on observed hydraulic heads on either side of sheetpile (AECOM, 2016)
Horizontal Flow Rate from Leakage at one opening Sheetpile, Qs	0	Qs= Kh*Ah*Ih*28.3168 liter/cf	liters per day (appropriate unit conversions applied)
Number of openings at Sheetpile, Ns	86	L/W/2	assume opening for every 2 sheetpiles
Number of Interlocks of sheetpile, Ni	86	L/W/2	assume interlock for every 2 sheetpiles
Horizontal flow rate at each interlock, Qi	0	NA	liters per day, based on calculations proposed by Selleijer et.al, 1995
Total horizontal flow from CCPW area to the amended area, Ft	0	Ft=Qi*Ns+Qi*Ni	liters per day
Concentration of Cr^{+6} in groundwater leaking from sheetpile adjacent to CCPW, Cadj	500	NA	mg/L, assumed
Amended Backfill Soils	**Values**	**Calculations**	
FB-H Applied	105	NA	short tons, from field tracking logs
FB-H Applied	95,235	FB-H applied * 907.185 kg/ton	kg (appropriate unit conversions applied)
FB-H Amendment in the Soil Required to treat 1 gram of Cr^{+6} based on Stoichiometry, As	18.64	NA	gm FB-H/gm Cr^{+6}, per stoichiometry to reduce Cr^{+6} to Cr^{+3} (Attachment F)
FB-H Dosage, X	0.007	NA	percentage by weight
Porosity of Dense Graded Aggregate (DGA), θ_{DGA}	0.26	NA	Reference: Capillary Break Design Report (GAG-036K) (AECOM, 2017)
Cr^{+6} concentration (pre-remediation) in the shallow zone	100	NA	mg/L, average concentration from 132-MW2A
Amendment Depth	5.5	NA	ft
Mass of Cr^{+6} in open excavation reacting with FB-H	62	Area * Amendment depth * Cr^{+6} concentration * θ_{DGA} * (28.3168 L/ft^3) * (kg/10^6 mg)	kg (appropriate unit conversions applied)
Amount of FB-H exhausted by initial reaction with Cr^{+6}, FB-H Exhausted	1,155	(Mass of Cr^{+6} in excavation) * As	kg (appropriate unit conversions applied)
Remaining FB-H for long term reduction, FB-H Remaining	94,080	(FB-H Applied) - (FB-H exhausted)	kg (appropriate unit conversions applied)
FB-H Longevity	**Values**	**Calculations**	
Flux of Cr^{+6} per year from Intermediate Zone, F	0	F =((Cg/Rf)*365 days/year*Q)/10^6 mg/Kg	flux of Cr^{+6} from intermediate zone (kg/year) (appropriate unit conversions applied)
Flux of Cr^{+6} per year from adjacent CCPW area , Fadj	0	Fadj=((Cadj/Rf)*365 days/year*Ft)/10^6 mg/Kg	flux of Cr^{+6} from adjacent CCPW area (kg/year) (appropriate unit conversions applied)
Flux of Oxygen from Shallow and Intermediate Zone per year, Fo	0.73	Fo = Foi+Fop	flux of DO (kg/year)
Duration of FB-H Longevity Based on Combined effect of Stoichiometric Demand for Cr^{+6} Flux and Oxygen Flux, Tf	**3,190**	Tf = FB-H Remaining/(As*F+ As*Fadj + ODF*Fo)	years, longevity based on combined effect of oxygen flux and Cr^{+6} flux, excluding FB-H initially exhausted
Minimum quantity of FB-H required to sustain for 100 years, W_{100}	**3.3**	W_{100} = 100*((As*F*0.0011 Ton/Kg) + (ODF*Fo*0.0011 Ton/Kg))	tons (appropriate unit conversions applied)
Minimum thickness of FB-H amended soils to sustain for 100 years, d_{100}	**0.5**	d_{100} = W_{100}/(A*ρb*X/27 cf/cy)	ft of amended soil (appropriate unit conversions applied)
Minimum quantity of FB-H required to sustain for 30 years, W_{30}	**1.0**	W_{30} = W_{100}*0.3	tons
Minimum thickness of FB-H amended soils to sustain for 30 years, d_{30}	**0.2**	d_{30} = d_{100}*0.3	ft of amended soil

Notes:
* A negative hydraulic gradient indicates downward flow, and a positive value indicates upward flow.
Units from conversion factors are provided with them and the units for the individual parameter are under the Units/Description column.

CCPW - chromate chemical production waste
cf - cubic feet
cf/day - cubic feet per day
ft - feet
FB-H - FerroBlack®-H
gm - grams
gm/gm - gram per gram
kg - kilograms
L/kg - liters per kilogram
mg/Kg - milligram per kilogram
mg/L - milligram per liter
NA - Not Applicable
sf - square feet
ton/cy - ton per cubic yard
cc - cubic centimeter
cy - cubic yard

References:

AECOM, 2017. GAG-036K: Draft Capillary Break Design Report. May.
AECOM, 2016. GW-006D: Site-Wide Groundwater Summary Report (April 2015 through March 2016). June.
NJDEP, 2015. Discharge Approval and Monitoring Requirement Associated with Permit-By-Rule Discharge Authorization for PPG Industries (COPR). June.
Selleijer, J.B.; Cools, J. P. A. E.; Decker, J.; Post, W. J.; 1995. Hydraulic Resistance of Sheetpile Joints. Journal of Geotechnical Engineering. Vol 121, Issue 2. February 1995.
Todd, D.K., 1980. Groundwater Hydrology [2nd Edition]. Wiley, New York. 552 pp.

Attachment C
Longevity Evaluation for FerroBlack®-H Amended Backfill Soils
Garfield Avenue Group of Sites
PPG, Jersey City, New Jersey

Estimation of FerroBlack®-H Longevity at Phase 3B (0.7% Amendment Area)

This FerroBlack®-H longevity estimate assumes the following:

The annual Cr^{+6} groundwater flux is constant and is based on the most current groundwater and soil concentration data;

The upward migration of Cr^{+6} in groundwater is subject to retardation, which is estimated from the apparent partitioning calculated as the ratio of the soil and aqueous chromium concentrations;

The Cr^{+6} and dissolved oxygen (DO) will be the primary oxidizing constituents of the reductants in FB-H; and

The vertical hydraulic conductivity is assumed to be 10% of the horizontal hydraulic conductivity.

- Data Input Cell
- Variables for each phase
- Data Output Cell

Intermediate Zone Aquifer Properties	**Values**	**Calculations**	**Units/Description**
Horizontal Hydraulic Conductivity, Kh	14.26	NA	ft per day, geomean of the Kh values observed during tests conducted at 137-MW1B & 137-MW2B
Vertical Hydraulic Conductivity, Kv	1.43	NA	ft per day, assumed 10% of Kh (Reference: Groundwater Hydrology [2nd ed.] by D. K. Todd. Wiley, New York, 1980. 552 pp.)
Average Vertical Hydraulic Gradient (I)*	-0.0609	Groundwater flow is downward	ft/ft, based on the transducer data from June 2016 to December 2016.
Soil Bulk Density,ρb	1.62	NA	ton/cy, based on the values used in the approved groundwater pilot study Permit-By-Rule (PBR) application. Discharge Approval and Monitoring Requirement Associated with Permit-By-Rule Discharge Authorization for PPG Industries (COPR) (NJDEP, 2015)
Total Porosity, θT	30%	NA	percentage, same reference as mentioned above (NJDEP, 2015)
Area, A	25,780.53	NA	sf, Figure 3-4 of Site-Wide GW Summary Report - April 2015 through March 2016 (AECOM, 2016)
Upward Vertical Flow Rate, Qcf	0	Qcf=Kv*I*A, no flow upward as the gradient is downward	cf/day
Upward Vertical Flow Rate, Q	0	Q=Kv*I*A*28.3168 liter/cf	Liters/day (appropriate unit conversions applied)
Oxidative Demand from Precipitation in Shallow Zone	**Values**	**Calculations**	
Annual Precipitation, P	46.42	NA	inches/year, reference: www.usclimatedata.com
Annual Infiltration Rate, i%	20%	NA	based on HELP modeling (Attachment E).
Annual Total Infiltration, I	564,658	I = (A*P*i%/12)*28.3168 liter/cf	Liters/year (appropriate unit conversions applied)
Dissolved Oxygen due to Precipitation, DO (Assumed from the Phase 2A area)	2.18	NA	mg/L, an average DO from four shallow wells in Phase 2A area (unamended), measured in Dec. 2016, was used. These four wells are 114-P2A-MW101S, 114-P2A-MW102S,114-P2A-MW103S, and 114-P2A-MW104S.
Flux of Dissolved Oxygen from Precipitation, Fop	1	Fop= (DO*I)/10^6 mg/kg	kg/year (appropriate unit conversions applied)
Oxygen Demand for FB-H to Reduce 1 gram of Oxygen, ODF	40.37	NA	gm FB-H/gm O_2, per stoichiometry (Attachment F)
Annual Oxidative Demand from Precipitation, OS	49.7	OS =Fop*ODF	kg FB-H/year (appropriate unit conversions applied)
Oxidative Demand from Intermediate Zone	**Values**	**Calculations**	
Dissolved Oxygen in Groundwater, Doi	0.49	NA	mg/L, June 2016 (137-P3B-MW102I)
Upward Flux of Dissolved Oxygen from Intermediate Zone, Foi	0.00	Foi=(Q*Doi/10^6)*365 days/year	kg/year
Cr^{+6} Concentration in Intermediate Zone	**Values**	**Calculations**	
Average Concentration of Cr^{+6} in Groundwater, Cg	0.72	NA	mg/L, average of last four quarters of data from 137-P3B-MW101I & 137-P3B-MW102I (September 2015 through June 2016)
Cr^{+6} Concentration (Highest) in Soil in Intermediate Zone, Cs	3	NA	mg/kg, from 137-P3B-MW101I (40.0 - 40.5 ft)
Distribution coefficient, Kd	4.18	Cs/Cg	L/kg
Retardation Coefficient, Rf	27.70	Rf = 1+(ρb*(1.18655(gm/cc)/(ton/cy))/θT)*Kd	unitless (appropriate unit conversions applied)
Cr^{+6} Concentration from Adjacent CCPW Area	**Values**	**Calculations**	
Depth of FerroBlack Amended Area sheetpile, D	10	NA	ft, based on cross-sections and groundwater elevation maps (AECOM, 2016)
Width of entire sheetpile wall adjacent to the area, L	350	NA	ft
Width of each sheetpile unit,W	2.33	NA	ft
Opening between sheetpiles, Os	0.08	NA	ft
Area of opening, Ah	1	Ah= D*L	sq ft
Leakage Area	1%	NA	assumed
Horizontal Hydraulic Gradient, Ih	0.00	ft/ft	ft/ft, based on observed hydraulic heads on either side of sheetpile (AECOM, 2016)
Horizontal Flow Rate from Leakage at one opening Sheetpile, Qs	0	Qs= Kh*Ah*Ih*28.3168 liter/cf	liters per day (appropriate unit conversions applied)
Number of openings at Sheetpile, Ns	75	L/W/2	assume opening for every 2 sheetpiles
Number of Interlocks of sheetpile, Ni	75	L/W/2	assume interlock for every 2 sheetpiles
Horizontal flow rate at each interlock, Qi	0	NA	liters per day, based on calculations proposed by Selleijer et.al, 1995
Total horizontal flow from CCPW area to the amended area, Ft	0	Ft=Qi*Ns+Qi*Ni	liters per day
Concentration of Cr^{+6} in groundwater leaking from sheetpile adjacent to CCPW, Cadj	500	NA	mg/L, assumed
Amended Backfill Soils	**Values**	**Calculations**	
FB-H Applied	180	NA	short tons, from field tracking logs
FB-H Applied	163,260	FB-H applied * 907.185 kg/ton	kg (appropriate unit conversions applied)
FB-H Amendment in the Soil Required to treat 1 gram of Cr^{+6} based on Stoichiometry, As	18.64	NA	gm FB-H/gm Cr^{+6}, per stoichiometry to reduce Cr^{+6} to Cr^{+3} (Attachment F)
FB-H Dosage, X	0.01	NA	percentage by weight
Porosity of Dense Graded Aggregate (DGA), θ_{DGA}	0.26	NA	Reference: Capillary Break Design Report (GAG-036K) (AECOM, 2017)
Cr^{+6} concentration (pre-remediation) in the shallow zone	100	NA	mg/L, average concentrations from 137-MW1A, 137-MW2A
Amendment Depth	17.0	NA	ft
Mass of Cr^{+6} in open excavation reacting with FB-H	323	Area * Amendment depth * Cr^{+6} concentration * θ_{DGA} * (28.3168 L/ft^3) * (kg/10^6 mg)	kg (appropriate unit conversions applied)
Amount of FB-H exhausted by initial reaction with $Cr^{+6,}$, FB-H Exhausted	6,015	(Mass of Cr^{+6} in excavation) * As	kg (appropriate unit conversions applied)
Remaining FB-H for long term reduction, FB-H Remaining	157,245	(FB-H Applied) - (FB-H exhausted)	kg (appropriate unit conversions applied)
FB-H Longevity	**Values**	**Calculations**	
Flux of Cr^{+6} per year from Intermediate Zone, F	0.00	F =((Cg/Rf)*365 days/year*Q)/10^6 mg/Kg	flux of Cr^{+6} from intermediate zone (kg/year) (appropriate unit conversions applied)
Flux of Cr^{+6} per year from adjacent CCPW area , Fadj	0	Fadj=((Cadj/Rf)*365 days/year*Ft)/10^6 mg/Kg	flux of Cr^{+6} from adjacent CCPW area (kg/year) (appropriate unit conversions applied)
Flux of Oxygen from Shallow and Intermediate Zone per year, Fo	1.23	Fo = Foi+Fop	flux of DO (kg/year)
Duration of FB-H Longevity Based on Combined effect of Stoichiometric Demand for Cr^{+6} Flux and Oxygen Flux, Tf	**3,164**	Tf = FB-H Remaining/(As*F+ As*Fadj + ODF*Fo)	years, longevity based on combined effect of oxygen flux and Cr^{+6} flux, excluding FB-H initially exhausted
Minimum quantity of FB-H required to sustain for 100 years, W_{100}	**5.5**	W_{100} = 100*((As*F*0.0011 Ton/Kg) + (ODF*Fo*0.0011 Ton/Kg))	tons (appropriate unit conversions applied)
Minimum thickness of FB-H amended soils to sustain for 100 years, d_{100}	**0.5**	d_{100} = W_{100}/(A*ρb*X/27 cf/cy)	ft of amended soil (appropriate unit conversions applied)
Minimum quantity of FB-H required to sustain for 30 years, W_{30}	**1.6**	W_{30} = W_{100}*0.3	tons
Minimum thickness of FB-H amended soils to sustain for 30 years, d_{30}	**0.2**	d_{30} = d_{100}*0.3	ft of amended soil

Notes:

* A negative hydraulic gradient indicates downward flow, and a positive value indicates upward flow.

Units from conversion factors are provided with them and the units for the individual parameter are under the Units/Description column.

CCPW - chromate chemical production waste
cf - cubic feet
cf/day - cubic feet per day
ft - feet
FB-H - FerroBlack®-H
gm - grams
gm/gm - gram per gram
kg - kilograms
L/kg - liters per kilogram
mg/Kg - milligram per kilogram
mg/L - milligram per liter
NA - Not Applicable
sf - square feet
ton/cy - ton per cubic yard
cc - cubic centimeter
cy - cubic yard

References:

AECOM, 2017. GAG-036K: Draft Capillary Break Design Report. May.

AECOM, 2016. GW-006D: Site-Wide Groundwater Summary Report (April 2015 through March 2016). June.

NJDEP, 2015. Discharge Approval and Monitoring Requirement Associated with Permit-By-Rule Discharge Authorization for PPG Industries (COPR). June.

Selleijer, J.B.; Cools, J. P. A. E.; Decker, J.; Post, W. J.; 1995. Hydraulic Resistance of Sheetpile Joints. Journal of Geotechnical Engineering. Vol 121, Issue 2. February 1995.

Todd, D.K., 1980. Groundwater Hydrology [2nd Edition]. Wiley, New York. 552 pp.

Estimation of FerroBlack®-H Longevity at Phase 3C (0.7% Amendment Area)

Data Input Cell
Variables for each phase
Data Output Cell

This FerroBlack®-H longevity estimate assumes the following:

The annual Cr^{+6} groundwater flux is constant and is based on the most current groundwater and soil concentration data;
The upward migration of Cr^{+6} in groundwater is subject to retardation, which is estimated from the apparent partitioning calculated as the ratio of the soil and aqueous chromium concentrations;
The Cr^{+6} and dissolved oxygen (DO) will be the primary oxidizing constituents of the reductants in FB-H; and
The vertical hydraulic conductivity is assumed to be 10% of the horizontal hydraulic conductivity.

Intermediate Zone Aquifer Properties	**Values**	**Calculations**	**Units/Description**
Horizontal Hydraulic Conductivity, Kh	3.80	NA	ft per day, from 114-MW19B
Vertical Hydraulic Conductivity, Kv	0.38	NA	ft per day, assumed 10% of Kh (Reference: Groundwater Hydrology [2nd ed.] by D. K. Todd. Wiley, New York, 1980. 552 pp.)
Average Vertical Hydraulic Gradient (I)*	0.1142	NA	ft/ft, based on the transducer data from June 2016 to December 2016.
Soil Bulk Density,ρb	1.62	NA	ton/cy, based on the values used in the approved groundwater pilot study Permit-By-Rule (PBR) application. Discharge Approval and Monitoring Requirement Associated with Permit-By-Rule Discharge Authorization for PPG Industries (COPR) (NJDEP, 2015)
Total Porosity, θT	30%	NA	percentage, same reference as mentioned above (NJDEP, 2015)
Area, A	27,110	NA	sf, Figure 3-4 of Site-Wide GW Summary Report - April 2015 through March 2016 (AECOM, 2016)
Upward Vertical Flow Rate, Qcf	1,177	Qcf=Kv*I*A	cf/day
Upward Vertical Flow Rate, Q	33,327	Q=Kv*I*A*28.3168 liter/cf	Liters/day (appropriate unit conversions applied)
Oxidative Demand from Precipitation in Shallow Zone	**Values**	**Calculations**	
Annual Precipitation, P	42.82	NA	inches/year, reference: www.usclimatedata.com
Annual Infiltration Rate, i%	20%	NA	based on HELP modeling (Attachment E).
Annual Total Infiltration, I	547,728	I = (A*P*i%/12)*28.3168 liter/cf	Liters/year (appropriate unit conversions applied)
Dissolved Oxygen due to Precipitation, DO (Assumed from the Phase 2A area)	2.18	NA	mg/L, an average DO from four shallow wells in Phase 2A area (unamended), measured in Dec. 2016, was used. These four wells are 114-P2A-MW101S, 114-P2A-MW102S,114-P2A-MW103S, and 114-P2A-MW104S.
Flux of Dissolved Oxygen from Precipitation, Fop	1	Fop= (DO*I)/10^6 mg/kg	kg/year (appropriate unit conversions applied)
Oxygen Demand for FB-H to Reduce 1 gram of Oxygen, ODF	40.37	NA	gm FB-H/gm O_2, per stoichiometry (Attachment F)
Annual Oxidative Demand from Precipitation, OS	48.2	OS =Fop*ODF	kg FB-H/year
Oxidative Demand from Intermediate Zone	**Values**	**Calculations**	
Dissolved Oxygen in Groundwater, Doi	0.31	NA	mg/L, June 2016 (133-P3C-MW101I)
Upward Flux of Dissolved Oxygen from Intermediate Zone, Foi	3.77	Foi=(Q*Doi/10^6)*365 days/year	kg/year
Cr^{+6} Concentration in Intermediate Zone	**Values**	**Calculations**	
Average Concentration of Cr^{+6} in Groundwater, Cg	0.002	NA	mg/L, average of last three quarters of data from 133-P3C-MW101I & 133-P3C-MW102I (March 2016 through September 2016)
Cr^{+6} Concentration (Highest) in Soil in Intermediate Zone, Cs	0.24	NA	mg/kg, from 133-P3C-MW101I (35.0 - 35.5 ft) (Samples were below detection limit of 0.24 mg/kg)
Distribution coefficient, Kd	147.92	Cs/Cg	L/kg
Retardation Coefficient, Rf	945.85	Rf = 1+(ρb*(1.18655(gm/cc)/(ton/cy))/θT)*Kd	unitless (appropriate unit conversions applied)
Cr^{+6} Concentration from Adjacent CCPW Area	**Values**	**Calculations**	
Depth of FerroBlack Amended Area sheetpile, D	54	NA	ft, based on cross-sections and groundwater elevation maps (AECOM, 2016)
Width of entire sheetpile wall adjacent to the area, L	800	NA	ft
Width of each sheetpile unit,W	2.33	NA	ft
Opening between sheetpiles, Os	0.08	NA	ft
Area of opening, Ah	4	Ah= D*L	sq ft
Horizontal Hydraulic Gradient, Ih	0.000	ft/ft	ft/ft, based on observed hydraulic heads on either side of sheetpile (AECOM, 2016)
Horizontal Flow Rate from Leakage at one opening Sheetpile, Qs	0.00	Qs= Kh*Ah*Ih*28.3168 liter/cf	liters per day (appropriate unit conversions applied)
Number of openings at Sheetpile, Ns	172	L/W/2	assume opening for every 2 sheetpiles
Number of Interlocks of sheetpile, Ni	172	L/W/2	assume interlock for every 2 sheetpiles
Horizontal flow rate at each interlock, Qi	0	NA	liters per day, based on calculations proposed by Selleijer et.al, 1995
Total horizontal flow from CCPW area to the amended area, Ft	0	Ft=Qi*Ns+Qi*Ni	liters per day
Concentration of Cr^{+6} in groundwater leaking from sheetpile adjacent to CCPW, Cadj	500	NA	mg/L, assumed
Amended Backfill Soils	**Values**	**Calculations**	
FB-H Applied	370	NA	short tons, as of 09/14/2016 from field logs
FB-H Applied	335,590	FB-H applied * 907.185 kg/ton	kg (appropriate unit conversions applied)
FB-H Amendment in the Soil Required to treat 1 gram of Cr^{+6} based on Stoichiometry, As	18.64	NA	gm FB-H/gm Cr^{+6}, per stoichiometry to reduce Cr^{+6} to Cr^{+3} (Attachment F)
FB-H Dosage, X	0.007	NA	percentage by weight
Porosity of Dense Graded Aggregate (DGA), θ_{DGA}	0.26	NA	Reference: Capillary Break Design Report (GAG-036K) (AECOM, 2017)
Cr^{+6} concentration (pre-remediation) in the shallow zone	100	NA	mg/L, average concentrations from MW9S, 114-MW19A
Amendment Depth	12.7	NA	ft
Mass of Cr^{+6} in open excavation reacting with FB-H	253	Area * Amendment depth * Cr^{+6} concentration * θ_{DGA} * (28.3168 L/ft^3) * (kg/10^6 mg)	kg (appropriate unit conversions applied)
Amount of FB-H exhausted by initial reaction with Cr^{+6}, FB-H Exhausted	4,725	(Mass of Cr^{+6} in excavation) * As	kg (appropriate unit conversions applied)
Remaining FB-H for long term reduction, FB-H Remaining	330,865	(FB-H Applied) - (FB-H exhausted)	kg (appropriate unit conversions applied)
FB-H Longevity	**Values**	**Calculations**	
Flux of Cr^{+6} per year from Intermediate Zone, F	0.00	F =((Cg/Rf)*365 days/year*Q)/10^6 mg/Kg	flux of Cr^{+6} from intermediate zone (kg/year) (appropriate unit conversions applied)
Flux of Cr^{+6} per year from adjacent CCPW area , Fadj	0	Fadj=((Cadj/Rf)*365 days/year*Ft)/10^6 mg/Kg	flux of Cr^{+6} from adjacent CCPW area (kg/year) (appropriate unit conversions applied)
Flux of Oxygen from Shallow and Intermediate Zone per year, Fo	4.97	Fo = Foi+Fop	flux of DO (kg/year)
Duration of FB-H Longevity Based on Combined effect of Stoichiometric Demand for Cr^{+6} Flux and Oxygen Flux, Tf	**1,651**	Tf = FB-H Remaining/(As*F+ As*Fadj + ODF*Fo)	years, longevity based on combined effect of oxygen flux and Cr^{+6} flux, excluding FB-H initially exhausted
Minimum quantity of FB-H required to sustain for 100 years, W_{100}	**22.1**	W_{100} = 100*((As*F*0.0011 Ton/Kg) + (ODF*Fo*0.0011 Ton/Kg))	tons (appropriate unit conversions applied)
Minimum thickness of FB-H amended soils to sustain for 100 years, d_{100}	**1.9**	d_{100} = W_{100}/(A*ρb*X/27 cf/cy)	ft of amended soil (appropriate unit conversions applied)
Minimum quantity of FB-H required to sustain for 30 years, W_{30}	**6.6**	W_{30} = W_{100}*0.3	tons
Minimum thickness of FB-H amended soils to sustain for 30 years, d_{30}	**0.6**	d_{30} = d_{100}*0.3	ft of amended soil

Notes:
* A negative hydraulic gradient indicates downward flow, and a positive value indicates upward flow.
Units from conversion factors are provided with them and the units for the individual parameter are under the Units/Description column.

CCPW - chromate chemical production waste
cf - cubic feet
cf/day - cubic feet per day
ft - feet
FB-H - FerroBlack®-H
gm - grams
gm/gm - gram per gram
kg - kilograms
L/kg - liters per kilogram
mg/Kg - milligram per kilogram
mg/L - milligram per liter
NA - Not Applicable
sf - square feet
ton/cy - ton per cubic yard
cc - cubic centimeter
cy - cubic yard

References:

AECOM, 2017. GAG-036K: Draft Capillary Break Design Report. May.
AECOM, 2016. GW-006D: Site-Wide Groundwater Summary Report (April 2015 through March 2016). June.
NJDEP, 2015. Discharge Approval and Monitoring Requirement Associated with Permit-By-Rule Discharge Authorization for PPG Industries (COPR). June.
Selleijer, J.B.; Cools, J. P. A. E.; Decker, J.; Post, W. J.; 1995. Hydraulic Resistance of Sheetpile Joints. Journal of Geotechnical Engineering. Vol 121, Issue 2. February 1995.
Todd, D.K., 1980. Groundwater Hydrology [2nd Edition]. Wiley, New York. 552 pp.

ATTACHMENT D

Hydraulic Conductivity Values

Attachment D

Hydraulic Conductivity Values

Garfield Avenue Group of Sites

PPG, Jersey City, New Jersey

Excavation Phase and FB-H Dosage (% by wt.)	K_H Value used from	K_H (ft/day)	Note
IRM #1 (0.7%)	Phase 3C (114-MW19B)	3.80	Nearest phase with similar geology, i.e., presence of meadow mat
Phase 1A (2.8%)	Phase 1A	0.86	Geometric mean of K_H measurements from 3 wells (114-MC-EW103, 114-MC-PZ103 and 114-MC-PZ203)
Phase 1B (0.7%)	Phase 1A	0.86	Geometric mean of K_H measurements from 3 wells (114-MC-EW103, 114-MC-PZ103 and 114-MC-PZ203)
Phase 1C (2.8%)	Phase 1A	0.86	Geometric mean of K_H measurements from 3 wells (114-MC-EW103, 114-MC-PZ103 and 114-MC-PZ203)
Phase 2B-1 (2%)	Phase 3C (114-MW19B)	3.80	Nearest phase with similar geology, i.e., presence of meadow mat
Phase 2B-2 (0.7%)	Phase 1A	0.86	Geometric mean of K_H measurements from 3 wells (114-MC-EW103, 114-MC-PZ103 and 114-MC-PZ203)
Phase 2B-3 (0.7%)	Phase 3C (114-MW19B)	3.80	Nearest phase with similar geology, i.e., presence of meadow mat
Phase 2B-4 (0.7%)	Phase 3C (114-MW19B)	3.80	Nearest phase with similar geology, i.e., presence of meadow mat
Phase 3A (0.7%)	Phase 3C (114-MW19B)	3.80	Nearest phase with similar geology, i.e., presence of meadow mat
Phase 3B (0.7%)	Phase 3B	14.26	Geometric mean of K_H measurements from 2 wells (137-MW1B and 137-MW2B)
Phase 3C (0.7%)	Phase 3C (114-MW19B)	3.80	K_H value measured only from well 114-MW19B

Notes:

FB-H - FerroBlack®-H

ft - feet

K_H - horizontal hydraulic conductivity

wt. - weight

ATTACHMENT E

HELP Model

Attachment E
HELP Model
Garfield Avenue Group of Sites
PPG, Jersey City, New Jersey

In order to estimate the recharge from precipitation, AECOM used the Hydrologic Evaluation of Landfill Performance (HELP) model. The HELP model is a water budget model that is designed to estimate leachate rates for landfill design purposes. However, the water budgeting portion of the model can be applied to sites more generally. Precipitation is generated synthetically based on a local climatic database and then the components of the water budget are calculated based on modeling inputs (i.e., soils, vegetation, land use). By running the model for a long time, long-term steady-state water budget components (including recharge) can be estimated.

This modeling was completed for three scenarios:

- Current conditions (Scenario 1)
    - 4 inches top layer of gravel
    - 198 inches of densely graded aggregate
    - 36 inches of meadow mat
- Current Conditions (Scenario 2)
    - 4 inches top layer of gravel
    - 96 inches of densely graded aggregate
    - 6 inches of capillary break (gravel)
    - 96 inches of densely graded aggregate
    - 36 inches of meadow mat
- Future conditions (Scenario 3)
    - Same as Scenario 2
    - Assumes sparse vegetation

The attached tables itemize the input parameters. The average annual precipitation in Jersey City is 46.42 inches (http://www.usclimatedata.com/climate/jersey-city/new-jersey/united-states/usnj0234).

The output indicates that the calculated/simulated recharge rates are 8.14, 7.87, and 7.75 inches per year for each of the three scenarios respectively. **Therefore, an estimate of 8 inches per year may be used for design purposes.**

The results are sensitive to several significant inputs:

- The curve number, which estimates runoff;
- The presence/absence and role of the capillary gravel layer;
- The hydraulic conductivity of the meadow mat, which is the limiting factor for flux from the shallow to the intermediate groundwater zones; and
- The vegetative cover, which may be variable over time, particularly in times prior to redevelopment.

The estimate of recharge made using the HELP model is based on a conceptual site model. For comparison, in pristine (relatively undeveloped, fairly permeable) watersheds where precipitation is, for example, 40 inches a year, recharge is conventionally estimated at around one-third to one-half of that amount, or 12 to 20 inches a year. The remaining precipitation is subject to runoff or evapotranspiration.

ATTACHMENT F

Reductive Capacity of FerroBlack®-H Stoichiometric Calculations

Attachment F
Reductive Capacity of FerroBlack®-H Stoichiometric Calculations
Garfield Avenue Group of Sites
PPG, Jersey City, New Jersey

I. Reductive Capacity of FerroBlack®-H to reduce Cr^{+6} to Cr^{+3}

Element	Composition (%)	Mass of FB-H (lb)	Molar weight (g/mol)	Mass (lb)	Mass (g)	Number of Moles in 1 ton FB-H	Electrons Option # 1	Electrons Option # 2	Electrons Option # 3	Electrons Option # 4
Fe	4.75%	2000	55.85	95	43,130	772	772	772	772	772
S	3.60%	2000	32.06	72	32,688	1,020	8,157	6,118	4,078	2,039
Total Moles of Electrons in 1 ton FB-H							8,929	6,890	4,851	2,811
Number of Electrons Transferred During Cr^{+6} to Cr^{+3} reduction							3	3	3	3
Moles of Cr^{+6} to Cr^{+3} Able to be Reduced							2,976	2,297	1,617	937
Molar Mass of Cr (g/mol)							52	52	52	52
Cr^{+6} (g) Able to be Reduced							154,739	119,400	84,061	48,722
Cr^{+6} (lb) Able to be Reduced							341	263	185	107
Grams of FB-H needed to reduce 1 g of Cr^{+6} to Cr^{+3}							5.87	7.60	10.80	18.64

II. Reductive Capacity of FerroBlack®-H to reduce O_2 to H_2O

Element	Composition (%)	Mass of FB-H	Molar weight (g/mol)	Mass (lb)	Mass (g)	Number of Moles in 1 ton FB-H	Electrons Option # 1	Electrons Option # 2	Electrons Option # 3	Electrons Option # 4
Fe	4.75%	2000	55.85	95	43,130	772	772	772	772	772
S	3.60%	2000	32.06	72	32,688	1,020	8,157	6,118	4,078	2,039
Total Moles of Electrons in 1 ton FB-H							8,929	6,890	4,851	2,811
Number of Electrons Transferred During O_2 to H_2O reduction							4	4	4	4
Moles of O_2 to H_2O Able to be Reduced							2,232	1,722	1,213	703
Molar Mass of O_2 (g/mol)							32	32	32	32
O_2 (g) Able to be Reduced							71,432	55,118	38,805	22,491
O_2 (lb) Able to be Reduced							157	121	85	50
Grams of FB-H needed to reduce 1 g of O_2 to H_2O							12.71	16.47	23.40	40.37

Option # 4 was used in the longevity calculations (Attachment C) as it provides the most conservative estimate of reductive capacity, for the same dosage of FB-H.

Notes:

1. Electron Transfer Scenarios:

Reactant		Potential Products	Electrons Released
S^{-2}	→	SO	2
S^{-2}	→	SO_2	4
S^{-2}	→	SO_3	6
S^{-2}	→	SO_4	8
Fe^{+2}	→	Fe^{+3}	1

These reactions may happen simultaneously or one at a time based on the immediate geochemical environment around each FeS molecule, the reaction kinetics, and the thermodynamics. In the reductive capacity calculations, most conservative estimates are used to compensate for this uncertainity.

2. Half-cell reactions:

   a. Reduction of Cr^{+6} to Cr^{+3}:

   $Cr^{+6} + 3e^{-} \longrightarrow Cr^{+3}$

   b. Reduction of O_2 to H_2O:

   $O_2 + 4H^{+} + 4e^{-} \longrightarrow 2H_2O$

3. These stoichiometric calculations assume that all of the FeS mixes into the solution and there is no surface absorption of FeS particles.

Cr^{+3} - trivalent chromium
Cr^{+6} - hexavalent chromium
FB-H - FerroBlack®-H
g - grams
H_2O - water
lb - pounds
mol - moles
O_2 - molecular oxygen

ATTACHMENT G

Responses to Comments on GW-028: Performance and Longevity Evaluation for Site Wide FerroBlack®-H Amended Backfill

AECOM
30 Knightsbridge Road, Suite 520
Piscataway, NJ 08854
T +1-732-564-3600

Memorandum

To	Tom Cozzi, NJDEP	Page 1
CC	Ronald Riccio, Site Administrator James Ray, Site Administrator PM Nancy Colson, Site Administrator Assistant David Doyle, NJDEP Prabal Amin, WESTON Solutions Laura Amend-Babcock, WESTON Solutions David Spader, ERFS Bhavini Doshi, City of Jersey City Joe Cunha, City of Jersey City Mark Terril, PPG Jody Overmyer, PPG Rich Feinberg, PPG Scott Mikaelian, AECOM	
Subject	Response to Comments on GW-028: Performance and Longevity Evaluation for Site Wide FerroBlack$^{®}$-H Amended Backfill Garfield Avenue Group Chromium Sites, Jersey City, New Jersey	
From	Lucas Hellerich, AECOM Sachin Sharma, AECOM Shree Ravi, AECOM	
Date	June 26, 2017	

On behalf of PPG, AECOM has prepared this memorandum to provide responses to comments received on June 2, 2017, from Weston Solutions, Inc. (Weston), on behalf of the New Jersey Department of Environmental Protection (NJDEP), on the *Performance and Longevity Evaluation for Site Wide FerroBlack$^{®}$-H Amended Backfill* memorandum submitted as an appendix to the *Draft Capillary Break Design Final Report* on May 2, 2017.

Comments received and PPG's/AECOM's responses are provided below:

1. ***<u>Comment #1</u>:*** <u>General Comment</u>: The basis for calculation on the longevity does not take into account the amount of FerroBlack-H (FB-H) that was expended when soils were backfilled "in the wet." The report should evaluate and discuss the amount of FB-H expended by contaminated shallow groundwater present in the open excavations at the time of initial backfill placement and how that impacts the remaining FB-H available to address the chromium mass flux from intermediate groundwater and unremediated areas.

Response to Comment #1:

The amount of FerroBlack®-H (FB-H) expended through the reaction with contaminated shallow groundwater (that was assumed to enter the excavation following placement of the FB-H amended backfill) is relatively much lower than the amount of FB-H applied at the Site. This is shown by the revised longevity estimates that account for the amount of FB-H initially expended by the reaction with contaminated shallow groundwater at the time of backfill placement. Attachment C (Longevity Evaluation for FerroBlack®-H Amended Backfill Soils) has been revised to incorporate the amount of FB-H initially expended. Table 3 (summary of longevity estimates) has also been revised. An estimate of the average pre-remediation shallow groundwater concentrations of hexavalent chromium (Cr^{+6}) at different areas of the Site was used to calculate the mass of FB-H that would react with the Cr^{+6} contained in one pore volume of shallow groundwater that entered the excavation following placement of the backfill. It was assumed that some of the FB-H would initially be exhausted during reaction of the Cr^{+6} with the soluble portion of the FB-H. Therefore, this estimated mass of FB-H was subtracted from the total applied mass of FB-H that was blended into the clean backfill, and the resulting mass of FB-H was used to estimate the longevity of the amendment. These revisions do not impact the conclusions of this evaluation. The available FB-H was still sufficient to maintain reducing conditions for a minimum of 200 years for all areas, and for longer time periods for select areas.

2. ***<u>Comment #2</u>:*** <u>General Comment:</u> The rate of reaction between FB-H and hexavalent chromium is pH dependent. Please confirm that the change in pH conditions (from alkaline to neutral conditions) would continue to support reduction of hexavalent chromium in the groundwater and include supporting information.

Response to Comment #2:

Yes, the change in the pH conditions from alkaline to neutral conditions would continue to support reduction of Cr^{+6}. The research articles listed below support the conclusion that the Cr^{+6} will continue to be reduced to Cr^{+3} at the pH range present in the shallow zone at the Site.

1. Chen J, Chen, R., and Hong, Mei. 2015. *Influence of pH on hexavalent chromium reduction by Fe (II) and sulfide compounds*. Water Science Technology; 72(1): 22-8.

2. Ignaz J. Buerge, et al. 1997. *Kinetics and pH dependence of Chromium (VI) reduction by Iron (II)*. Swiss Federal Institute for Environmental Science and Technology (EAWAG), CH-8600 Duebendorf, Switzerland; 31(5), pp 1426-1432.

3. Lan, Y-Q., Yang, J-X. and Deng, B. 2006. *Catalysis of Dissolved and Adsorbed Iron in Soil Suspension for Chromium (VI) Reduction by Sulfide*. Pedosphere 16(5), pp 572-578

In summary, this research indicates that both iron and sulfide can independently reduce Cr^{+6} to Cr^{+3}; however, the combined effect of an “iron sulfide’ (the main reactive agent in FB-H) was shown to be greater than the sum of either iron or sulfide treatment, individually, in the relevant pH range of the shallow zone. Therefore, if the pH of the system changes, the use of FB-H allows for continued Cr^{+6} reduction.

In the shallow zone where backfill was amended with FB-H, the pH ranges from 5.78 s.u. to 7.65 s.u., with a median pH of 6.77 s.u., with the exception of one well (MW-Morris 1A in Phase 1A, pH = 11.07 s.u.). These values were based on data that was collected between March and September 2016.

3. ***Comment #3:*** Section 4.2 Geochemistry -Sulfates and Sulfides, Page 9: Please support the reported trend of sulfide levels in groundwater with currently-available data. Please also establish a correlation between the rate of sulfide consumption and the rate of reduction in hexavalent chromium. This correlation should be used to substantiate the modeling output.

   Response to Comment #3:

   FB-H is a suspension of soluble and insoluble sulfides. Since the soluble portion of FB-H is only 1 – 2% by weight, it is exhausted faster than the insoluble portion of the FB-H. The insoluble sulfides act as a long-term, slow-releasing source of sulfide that mitigates the recontamination of clean backfill with Cr^{+6} from the intermediate zone groundwater. In phases where FB-H-amended backfill has been placed, sulfide concentrations in groundwater samples collected and analyzed between October 2014 and December 2016 were less than the detection limit in 95 of the 119 samples collected. Samples collected from six wells screened within amended fill (i.e., 114-MC-MW102S, 114-P1B-MW102S, 114-P2B1-MW103S, 114-P2B4-MW102S, 137-P3B-MW101S, and MW-Morris1A) contained detectable amounts of sulfide. However, the concentration trend of sulfides does not appear to directly correlate with the decline in Cr^{+6} concentrations at these locations, which have been less than 70 micrograms per liter (ug/L) since the first sampling event. Prior to soil remediation, groundwater samples were not analyzed for sulfide to provide a basis for comparison of pre- and post-remediation sulfide levels. Therefore, there is no pre-excavation baseline data for sulfide to establish a correlation between the rate of sulfide consumption and Cr^{+6} reduction as a result of FB-H application.

4. ***Comment #4:*** Section 4.3 Non-Chromium Target Analyte List, Page 9: FB-H reduces other metals to stable forms and those metals will be competing with hexavalent chromium. Based upon this observation, these TAL metals should be included in the model and the rate of sulfide consumption by these metals should be evaluated.

   Response to Comment #4:

   While FB-H can react with metals in groundwater such as arsenic (As), mercury (Hg), cadmium (Cd), etc., in addition to Cr^{+6}, the pre-remediation concentrations of these metals are considerably lower than that of Cr^{+6}. For example, prior to soil remediation, the average Cr^{+6} concentrations at the Site, in areas where FB-H-amended backfill was subsequently utilized, were greater than 200,000 ug/L. In comparison, the average pre-remediation concentrations of other metals (e.g., As, antimony [Sb], lead [Pb] and nickel [Ni]) were less than 500 ug/L.

   A comparison of average Cr and Cr^{+6} concentrations in the shallow zone in areas of the Site that have been backfilled with FB-H-amended fill indicates that there has been a reduction of over 99% compared to pre-remediation average concentrations. In addition, compared to pre-remediation averages, the concentrations of several Target Analyte List (TAL) metals, including As, Sb, Cd, cobalt (Co), copper (Cu), Ni, silver (Ag), thallium (Tl) and vanadium (V), have also reduced. The following summary table presents a comparison of pre- and post-soil remediation average concentrations of Cr, Cr^{+6}, and several TAL metals that could react with ferrous sulfide (FeS), in the shallow groundwater, in areas that were subsequently backfilled with FB-H-amended fill. As indicated on this table, the total average concentration of other metals of interest is approximately two orders of magnitude less than the average concentration of Cr or Cr^{+6} prior to soil remediation. Therefore, the presence of other metals in groundwater will not react with a significant amount of FB-H relative to the reaction of Cr^{+6} with FB-H.

Table A. Concentrations of Select Metals in the Shallow Zone Groundwater (Pre- and Post-Remediation)

Analyte	Average Pre-Remediation Shallow Zone Concentration (ug/L)	Number of Samples	Average Post-Remediation Shallow Zone Concentration (ug/L)	Number of Samples	Concentration Reduction
CHROMIUM (TOTAL)	***163,030***	80	166	123	100%
CHROMIUM (HEXAVALENT)	***223,379***	69	11	118	100%
ANTIMONY	117	78	11	119	90%
ARSENIC	110	54	23	119	79%
BARIUM	565	54	95	119	83%
BERYLLIUM	12	54	1	119	91%
CADMIUM	26	54	1	119	96%
COBALT	148	54	9	119	94%
COPPER	83	54	21	119	75%
LEAD	109	54	24	119	78%
MERCURY	0.36	54	0.09	119	75%
NICKEL	198	78	25	119	87%
SELENIUM	75	54	23	119	70%
SILVER	27	54	6	119	79%
THALLIUM	58	78	24	119	58%
VANADIUM	392	78	13	119	97%
ZINC	204	54	56	119	73%
Sum of Average Concentrations of Non-Chromium Metals (Pre-Remediation) =	***2,124 ug/L***				

Notes:
1. Concentrations have been rounded up to the nearest whole number.
2. Pre-remediation shallow zone groundwater concentration data is from analyses of samples collected between 2003 and 2014.
3. Post-remediation shallow zone groundwater concentration data is from analyses of samples collected between 2013 and 2017.
ug/L - micrograms per liter

5. ***Comment #5:*** Attachment C - Longevity Evaluation for Ferroblack –H Amended Backfill Soils:
   a) The distribution coefficient is pH dependent and it also depends upon the soil type. These parameters should be included in estimating the distribution/partition coefficient.

Response to Comment #5(a):

The pH of the intermediate zone groundwater at the Site in areas where amended backfill has been applied ranges from 5 s.u. to 12 s.u., averaging approximately 8 s.u, based on data collected from 2014 to 2016. The pH of the intermediate zone soils ranges from approximately 7 s.u. to 9 s.u., averaging 8.5 s.u., based on analyses of samples collected during the installation of intermediate zone monitoring wells in the same timeframe. However, the distribution coefficient, K_d, was calculated for each phase based on the observed concentration of Cr^{+6} in soil and groundwater in that phase, determined by laboratory analysis. Therefore, the values of K_d used in the longevity estimates have already accounted for any geochemical variations. It is not anticipated that the pH will change significantly during future remedial efforts, as they will be designed based on the pilot scale testing already completed in certain areas of the Site. The average pH of the intermediate zone groundwater in the pilot test areas was approximately 7.5 s.u. and values ranged from 6 to 10 s.u., as observed in the performance monitoring events conducted following the delivery of chemical and biological reagents. No change is recommended.

b) Provide the calculations used to estimate percent FB-H dosage values for the amended backfill in the different soil remediation phases.

Response to Comment #5(b):

The dosage rates of FB-H were derived from results observed during bucket testing and the subsequent pilot testing conducted at Site 114 performed in September 2011. These findings were previously presented in the following submittals to NJDEP:

- *Technical Execution Plan (TEP) – Southwestern Area Soil Excavation, PPG Site 114 – Garfield Avenue, Jersey City, New Jersey*, submitted on October 14, 2011. Section 7.3.1 of this TEP provides the design basis for the FB-H dosages, and the Appendix F provides an example of the amendment backfill calculations for the Morris Canal area and the Southwest area of Site 114;
- NJDEP commented on the dosage calculations on November 17, 2011 and the responses to these comments were incorporated in the subsequent *Permit-By-Rule (PBR) Request – Morris Canal East of IRM #1* application (dated February 24, 2012) submitted to NJDEP on February 28, 2012. This request also contained the Backfill Amendment Pilot Test Report (dated February 27, 2012) as well as the bucket test results; and
- *The Site-Wide Amended Fill PBR Request,* submitted to the NJDEP on August 30, 2012. Table 1 of this PBR lists the FB-H dosages and the maximum quantity of FB-H that was anticipated to be applied at each phase.

In the full-scale application, various dosing rates (ranging from 0% to 2.8% by weight) were applied, and were based on the observed concentrations of Cr^{+6} in the groundwater in the area. The FB-H dosing rates for the corresponding Cr^{+6} concentrations are listed below:

Cr^{+6} Concentration (mg/L)	Dosing of FB-H (by weight)
≥ 1,000	2.8%
≥ 100	2%
≥ 1 to 100	0.7%
≥ 0 to 1	0%

c) Please provide the basis for the assumption of a concentration of 500 mg/L of hexavalent chromium in the groundwater from sheet pile adjacent to CCPW.

Response to Comment #5(c):

A concentration of 500 mg/L of Cr^{+6} was assumed for the area(s) adjacent to the Chromate Chemical Production Waste (CCPW) area as a conservative value. The observed concentrations of the Cr^{+6} in these areas that are yet to be remediated are less than 500 mg/L. Based on the Cr^{+6} concentration isopleth maps submitted in *the Progress Report for Groundwater Pilot Study and FerroBlack-H Amended Backfill Permits-By-Rule – 2016 Fourth Quarter (October to December)* (AECOM, 2017), the maximum concentration of Cr^{+6} in the shallow zone in the remaining unpremeditated areas (i.e., Halladay Street North, Forrest Street, Carteret Avenue, etc.) is less than 100 mg/L. Therefore, the assumed value of 500 mg/L incorporates a considerable factor of safety and the estimates of longevity subsequently obtained are conservative. No change is recommended.

d) Please re-evaluate the calculations for the thickness of the FB-H amended soils. It is recommended that the total porosity be used for estimating the minimum thickness of amended fill required to sustain reductive capacity for 30 or 100 years.

Response to Comment #5(d):

The estimated thickness of the FB-H amended fill was calculated based on the following factors: the estimated number of tons of FB-H required maintaining reducing conditions for 100 years and 30 years; the area of the amended portion of the phase; and the soil bulk density (estimated to be 1.62 tons per cubic yards). Soil bulk density is calculated as the dry weight of the soil per unit volume. It is an inherent property that incorporates pore space/porosity (United States Department of Agriculture, Natural Resources Conservation Service – Soil Quality Indicators, June, 2008). No change is recommended.

e) The actual applied dosage of FB-H should be compared with the estimated FB-H dosage (calculated using the model) required to treat hexavalent chromium to confirm the longevity and performance of the amendment.

Response to Comment #5(e):

The longevity was evaluated based on the actual applied amount of FB-H. The dosages of FB-H (i.e., 0.7% to 2.8% by weight) referenced in this evaluation were based on the dosages that were applied within the different phases of the Site, as outlined in the August 2012 *Site-Wide FerroBlack®-H Amended Backfill PBR*. This evaluation did not independently calculate the required dosages. The longevity estimates used the actual applied tonnage (based on the field records) of FB-H. No change is recommended.

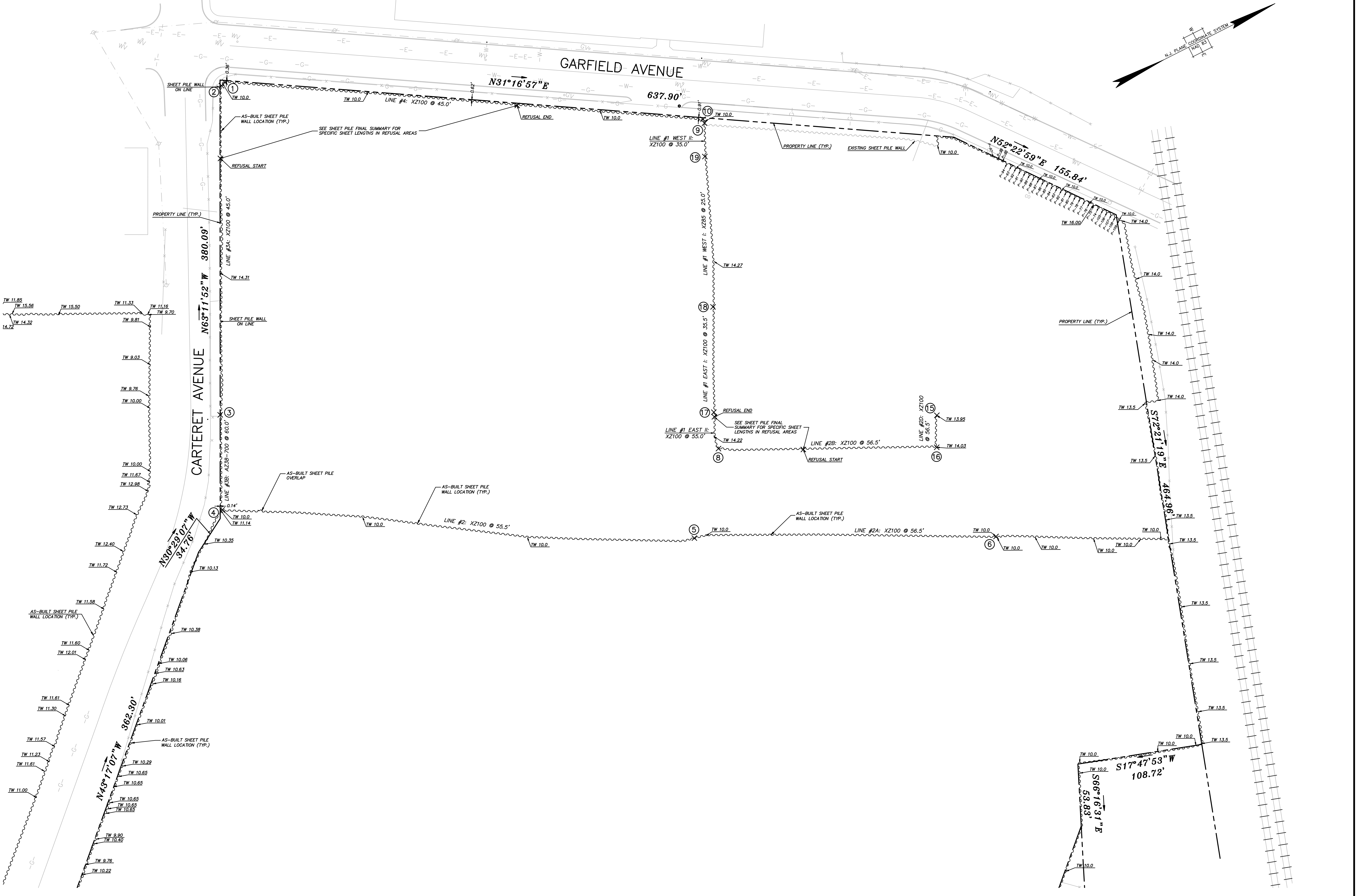
6. ***Comment #6:*** Attachment F – Reductive Capacity of Ferroblack-H Stoichiometric Calculations: Include half-cell reactions to confirm the number of atoms consumed to generate respective electron moles.

   Response to Comment #6:

   Attachment F has been revised to show half-cell reactions for the reduction of Cr^{+6} and oxygen.

Appendix F

Sheet Pile Wall As-Built – GA Group Sites



GENERAL NOTES

1. THE SOLE PURPOSE OF THIS PLAN IS TO SHOW THE AS-BUILT LOCATIONS AND ELEVATIONS OF THE SHEET PILING INSTALLATION AT THE PROJECT SITE.
2. AS-BUILT LOCATIONS AND ELEVATIONS WERE OBTAINED BY MASER CONSULTING, PA ON MARCH 23, 2012 & JUNE 12, 14, 18, & 26, 2013, JULY 15, 2013, DEC. 3, 11, 2014.
3. HORIZONTAL DATUM NAD 1983, VERTICAL DATUM NAVD 1988.

30 0 30 60
SCALE IN FEET
(1"=30')

REV.	DATE	DRAWN BY	DESCRIPTION
4.	1/7/15	RTH	REVISED TO SHOW UPDATED SHEET PILE LOCATIONS
3.	7/28/14	RTH	REVISED TO SHOW UPDATED SHEET PILE LOCATIONS
2.	7/22/13	RTH	REVISED TO SHOW UPDATED SHEET PILE LOCATIONS
1.	6/26/13	RTH	REVISED TO SHOW UPDATED SHEET PILE LOCATIONS

R. THOMAS HUGG
NEW JERSEY PROFESSIONAL
LAND SURVEYOR LIC. NO. 36737

MASER
CONSULTING P.A.
Consulting, Municipal & Environmental Engineers
Planners ■ Surveyors ■ Landscape Architects
State of N.J. Certificate of Authorization: 24GA27986500

MARMORA OFFICE
156 Stagecoach Road
Marmora, N.J. 08223
Phone (609) 390-1927
Fax (609) 390-0040
email: solutions @ maserconsulting.com

Regional Offices
Red Bank, N.J.
Clinton, N.J.
Hamilton, N.J.
Logan, N.J.
Mt. Arlington, N.J.
Chestnut Ridge, N.Y
Newburgh, N.Y.
Bethlehem, PA.

SHEET PILE WALL AS-BUILT
FOR
ENTACT, LLC
PPG INDUSTRIES SITE 114
900 GARFIELD AVENUE
JERSEY CITY HUDSON COUNTY NEW JERSEY

JOB NUMBER: 12000589A	DATE: APRIL 5, 2012
SCALE: 1" = 30'	LATEST REVISION: JAN. 7, 2015
INDEX NUMBER: MASU001165	DESIGN BY: RTH
SHEET NUMBER: 1 of 3	

GENERAL NOTES

1. THE SOLE PURPOSE OF THIS PLAN IS TO SHOW THE AS-BUILT LOCATIONS AND ELEVATIONS OF THE SHEET PILING INSTALLATION AT THE PROJECT SITE.
2. AS-BUILT LOCATIONS AND ELEVATIONS WERE OBTAINED BY MASER CONSULTING, PA ON MARCH 23, 2012 & JUNE 12, 14, 18, & 26, 2013, JULY 15, 2013, DEC. 3, 11, 2014.
3. HORIZONTAL DATUM NAD 1983, VERTICAL DATUM NAVD 1988.

30 0 30 60
SCALE IN FEET
(1"=30')

REV.	DATE	DRAWN BY	DESCRIPTION
4.	1/7/15	RTH	REVISED TO SHOW UPDATED SHEET PILE LOCATIONS
3.	7/28/14	RTH	REVISED TO SHOW UPDATED SHEET PILE LOCATIONS
2.	7/22/13	RTH	REVISED TO SHOW UPDATED SHEET PILE LOCATIONS
1.	6/26/13	RTH	REVISED TO SHOW UPDATED SHEET PILE LOCATIONS

R. THOMAS HUGG
NEW JERSEY PROFESSIONAL
LAND SURVEYOR LIC. NO. 36737

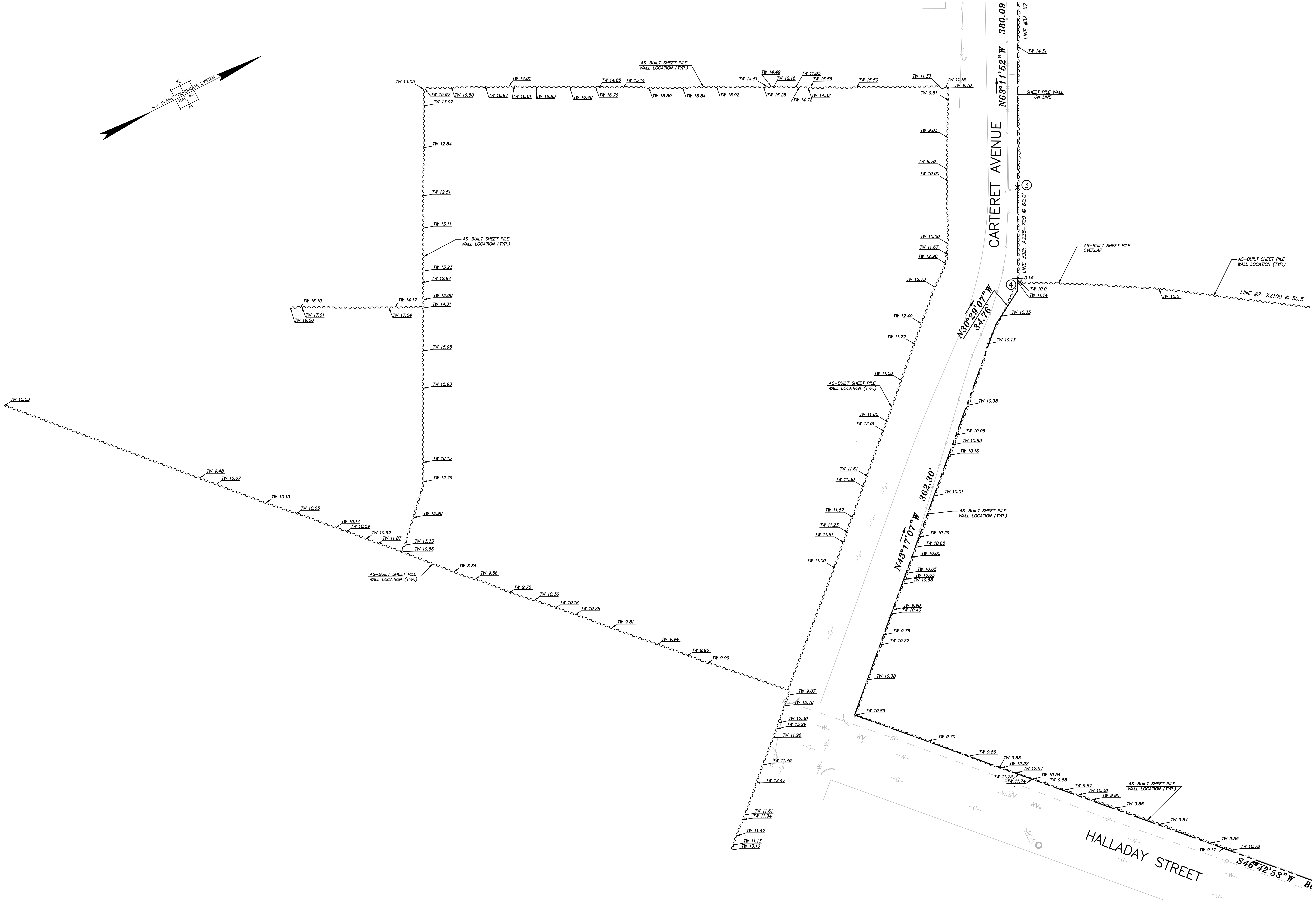
MASER
CONSULTING P.A.
Consulting, Municipal & Environmental Engineers
Planners ▪ Surveyors ▪ Landscape Architects
State of N.J. Certificate of Authorization: 24GA27986500

MARMORA OFFICE
156 Stagecoach Road
Marmora, N.J. 08223
Phone (609) 390-1927
Fax (609) 390-0040
email: solutions @ maserconsulting.com

Regional Offices
Red Bank, N.J.
Clinton, N.J.
Hamilton, N.J.
Logan, N.J.
Mt. Arlington, N.J.
Chestnut Ridge, N.Y
Newburgh, N.Y.
Bethlehem, PA.

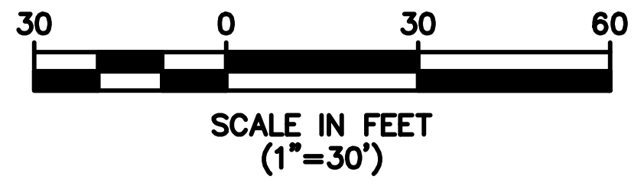
SHEET PILE WALL AS-BUILT
FOR
ENTACT, LLC
PPG INDUSTRIES SITE 114
900 GARFIELD AVENUE
JERSEY CITY HUDSON COUNTY NEW JERSEY

JOB NUMBER: 12000589A
DATE: APRIL 5, 2012
SCALE: 1" = 30'
LATEST REVISION: JAN. 7, 2015
INDEX NUMBER: MASU001165
DESIGN BY: RTH
SHEET NUMBER: 2 of 3



GENERAL NOTES

1. THE SOLE PURPOSE OF THIS PLAN IS TO SHOW THE AS-BUILT LOCATIONS AND ELEVATIONS OF THE SHEET PILING INSTALLATION AT THE PROJECT SITE.
2. AS-BUILT LOCATIONS AND ELEVATIONS WERE OBTAINED BY MASER CONSULTING, PA ON MARCH 23, 2012 & JUNE 12, 14, 18, & 26, 2013, JULY 15, 2013, DEC. 3, 11, 2014, SEPT. 15, 2015.
3. HORIZONTAL DATUM NAD 1983, VERTICAL DATUM NAVD 1988.



REV.	DATE	DRAWN BY	DESCRIPTION
5.	9/25/15	RTH	REVISED TO SHOW UPDATED SHEET PILE LOCATIONS
4.	1/7/15	RTH	REVISED TO SHOW UPDATED SHEET PILE LOCATIONS
3.	7/28/14	RTH	REVISED TO SHOW UPDATED SHEET PILE LOCATIONS
2.	7/22/13	RTH	REVISED TO SHOW UPDATED SHEET PILE LOCATIONS
1.	6/26/13	RTH	REVISED TO SHOW UPDATED SHEET PILE LOCATIONS

R. THOMAS HUGG
NEW JERSEY PROFESSIONAL
LAND SURVEYOR LIC. NO. 36737

MASER
CONSULTING P.A.
Consulting, Municipal & Environmental Engineers
Planners ■ Surveyors ■ Landscape Architects
State of N.J. Certificate of Authorization: 24GA27986500

MARMORA OFFICE
156 Stagecoach Road
Marmora, N.J. 08223
Phone (609) 390-1927
Fax (609) 390-0040
email: solutions @ maserconsulting.com

Regional Offices
Red Bank, N.J.
Clinton, N.J.
Hamilton, N.J.
Logan, N.J.
Mt. Arlington, N.J.
Chestnut Ridge, N.Y
Newburgh, N.Y.
Bethlehem, PA.

SHEET PILE WALL AS-BUILT
FOR
ENTACT, LLC
PPG INDUSTRIES SITE 114
900 GARFIELD AVENUE
JERSEY CITY HUDSON COUNTY NEW JERSEY

JOB NUMBER: 12000589A	DATE: APRIL 5, 2012
SCALE: 1" = 30'	LATEST REVISION: SEPT. 25, 2015
INDEX NUMBER: MASU001165	DESIGN BY: RTH
SHEET NUMBER: 4 of 4	

Appendix G

Restoration of GA Sites, Basis of Design

Restoration Capillary Break / Grading / Stormwater Management Basin Plan Basis of Design
Final Draft dated 3/8/17

The JCRA, City, and Hampshire offer the following comments and guidance regarding the Basis of Design for the restoration of the site:

1. PPG/DEP have established the design groundwater elevation for the capillary break at 13.2' NAVD88. This is inconsistent with the grades that currently exist on site post soil remediation (PPG has advised site grades in Phase 1 are currently +/- 11' NAVD88), the current road grades at Garfield Avenue (13' NAVD88) and the FEMA flood elevations for the area (12' NAVD88). With the design groundwater elevation at 13.2' NAVD88, the use of 2.8' of DGA or 6" of clean stone above the 13.2' elevation conflicts with some of the road grades established by JCRA. The JCRA and Hampshire have consistently voiced objections to the use of synthetic liners for the capillary break. Please consider the road profile, ie asphalt pavement section, as sufficient capillary break in non-residential areas to reduce or eliminate grading conflicts, where a sufficient capillary break cannot be achieved with the DGA or stone. Of particular concern is how the capillary break will tie into Garfield Avenue, given the grade differences. Notwithstanding elevation challenges, the use of DGA is the preferred capillary break material.

2. The need for the capillary break has been eliminated in areas of the Site through a combination of source removal and in situ treatment. In the areas where a capillary break is currently required, JCRA and Hampshire request that PPG be required to conduct further monitoring/ delineation to reduce the footprint of areas require a capillary break, and conduct further remediation to eliminate the areas of the Site where a capillary break is required.

3. As this remediation required major earthwork, we are of the opinion that the restoration must comply with the City's stormwater control ordinance, as the site discharges to the City's combined sewer system. The stormwater management system should provide for a basin with independent drainage on each block of the redevelopment plan so that an individual block can be built, while allowing for the stormwater systems on the adjacent block(s) to continue functioning. The proposed basins should be laid out such that the construction of Canal Way Park can also be facilitated without significant impacts to the adjacent basins. No basins shall encroach upon the new rights-of-way established in Canal Crossing. This will result in multiple basins, with independent drainage, that conform to the new street grid. In areas where a capillary break is not required, the bottom of the basins may remain at the current elevation of 11', provided other conditions identified herein are satisfied.

4. The right-of-way areas between basins shall be graded with Dense Grades Aggregate (DGA) to the Canal Crossing roadway elevations minus 12" to allow for the future pavement sections , and shall tie back into existing grades at the site perimeter. In no case shall the grades be higher than Canal Crossing grades, nor higher than existing grades at the perimeter along existing streets.

5. No berms shall be permitted within the existing rights-of-way (ie Garfield Ave, as was in the previous design).

6. The finished surface of the future rights-of-way may be left as DGA to create a road network within the site. A thin layer of clean stone is acceptable if required to comply with SESC permits. The finished surface of other areas are to be a minimum of 4" of top soil and a 'retention basin wildlife mix' which is a wildflower retention basin tolerant mix.
7. Permanent Ground Water Monitoring wells, if required, should be placed within the proposed Canal Crossing Rights of Way within future sidewalk areas so as to not conflict with future infrastructure. If this is not possible at this time, PPG must commit to relocating wells that are in conflict with future buildings and infrastructure.
8. PPG shall prepare a Drainage Report to calculate anticipated the stormwater runoff from the site and to design the appropriate stormwater controls to comply with all applicable soil conservation rules, State and Federal stormwater management rules, the Jersey City Stormwater Control Ordinance, and Jersey City Municipal Utilities Authority Rules and Regulations. Since the area falls within the 100 flood area, the Drainage Report shall address whether a Flood Hazard Area – Individual Permit, will be required.
9. Any drainage pipe system required to convey the runoff from the respective detentions basins shall be installed in the roadways and shall be designed to the NJDEP 25 year storm for Hudson County. PPG should refer to the Canal Crossing plans for size and location of anticipated stormwater pipes.
10. The basins shall provide 1 ft of freeboard, and shall completely drain within 72 hours. A minimum of 2 ft separation shall be provided to the Seasonal High Ground Water Elevation from the surface of the basin. It is our understanding that the elevation of 13.2' was established for the capillary break, and is not the Seasonal High Groundwater Elevation for the site. We request that PPG and its consultants provide data as to what they determine the actual groundwater elevation to be.
11. As the proposed basins will discharge into the City's combined sewer system they should, at a minimum, adhere to Chapter 345, Section 4(F)(d) of the Jersey City Stormwater Control Ordinance , requiring that the post-construction peak runoff rates for the 2, 10 and 100 year storm events be reduced to 50, 75, and 80 percent, respectively, of the pre-construction peak runoff rates.
12. The basins shall be designed such that the maximum water surface elevations in the basins do not exceed the grate elevations of the JCMUA inlets in the adjacent roadways, so as not to exacerbate flooding during storm events. The routings shall take into account the downstream tie in conditions under each storm event, and check valves shall be provided to prevent back flow into the basins.
13. Stormwater management measures shall be designed to reduce the post construction load of total suspended solids (TSS) in the stormwater generated from the water quality design storm by 80% of the anticipated load from the developed site expressed as an annual average.
14. The basin outlet structures shall be located at the outer edge of each basin to facilitate maintenance.
15. The Drainage Report shall consider that the site is at the downstream end of a much larger upstream watershed area. Any discharge from the proposed basins shall avoid direct connections to the 72:84" CSO and 96" CSO. Canal Crossing established storm water retainage requirements for each block. These volumes should be targeted for each basin that falls within the limits of PPG's remediation. These targets are identified in the following tables:

STORMWATER RETAINAGE BY BLOCK

Block	Lot	Required Volume (CF)
21404	2.01	26,043
21501.01	1	20,043
21501.02	1	24,543
21501.02	3	14,453
21501.02	4	17,725
21501.03	1	28,770
21501.04	1	21,407
21501.05	1	22,907
21501.06	1	22,907
21502.01	1	15,953
21502.03	1	15,953
21502.04	1	23,725
21503.01	1	16,907
21503.03	1	15,680
21503.04	1	15,953
21503.06	1	15,953
21503.07	1	29,179
21503.08	1	17,998
21503.09	1	17,180
21503.1	1	17,180
21503.11	1	17,180
21503.12	1	24,816
21503.13	1	16,089
21503.14	1	16,635
21503.15	1	23,861
21503.16	1	18,407
21509.01	1	16,907
21509.02	1	30,679
21510.01	1&2	22,225
21510.02	1	13,362
21510.03	1	24,543
21510.04	1	19,907
21510.05	1	19,225
22704	7.01	16,907
23707	23.01	26,724
23707	23.01	17,725

24301.01	1	18,134
24301.02	1	16,771
24301.03	1	21,134
24301.04	1	23,452
24301.05	1&2	22,498
TOTAL		**827,640**

STORAGE WITHIN CANAL WAY PARK

Storage Area	Required Volume (CF)	Detention Bottom Invert Elevation (FT)	Orifice Diameter (IN)
C1	8,486	10.50	3.00
C2	5,469	12.00	3.00
C3	5,846	10.00	3.00
C4	8,297	9.00	3.00
C5	6,600	9.00	3.00
C6	8,863	9.00	3.00
TOTAL	**43,560**		

Appendix H

Groundwater Elevations – Western Portion of Site

Appendix H
Groundwater Elevations - Western Portion of Site
Capillary Break Design - Final Report (Revision 2)
PPG, Jersey City, New Jersey

Well ID	Measurement Date	Groundwater Elevation (ft NAVD88)	Phase/Site
MW4A	12/22/2003	10.25	Carteret/South of Carteret
MW4A	1/20/2004	10.25	Carteret/South of Carteret
MW4A	9/30/2005	8.96	Carteret/South of Carteret
MW4A	12/13/2005	7.20	Carteret/South of Carteret
MW4A	05/19/2006	11.03	Carteret/South of Carteret
114-MW22A	2/12/2007	6.24	Carteret/South of Carteret
MW4A	2/12/2007	9.46	Carteret/South of Carteret
114-MW22A	5/7/2007	7.27	Carteret/South of Carteret
132-MW2A	5/7/2007	5.24	Carteret/South of Carteret
MW4A	5/17/2011	7.17	Carteret/South of Carteret
114-MW22A	5/17/2011	7.10	Carteret/South of Carteret
132-MW2A	5/17/2011	8.12	Carteret/South of Carteret
114-MW22A	6/15/2011	6.65	Carteret/South of Carteret
MW4A	6/15/2011	10.77	Carteret/South of Carteret
132-MW2A	6/17/2011	7.62	Carteret/South of Carteret
114-MW22A	11/22/2011	6.75	Carteret/South of Carteret
132-MW2A	11/22/2011	4.91	Carteret/South of Carteret
MW4A	11/22/2011	10.59	Carteret/South of Carteret
MW-35	3/5/2013	9.75	Carteret/South of Carteret
MW-34	3/5/2013	8.76	Carteret/South of Carteret
114-MW22A	3/5/2013	6.15	Carteret/South of Carteret
MW-34	4/23/2013	6.95	Carteret/South of Carteret
MW-35	4/29/2013	8.03	Carteret/South of Carteret
MW-34	6/4/2014	7.34	Carteret/South of Carteret
114-P1B-MW103S	6/4/2014	10.71	Carteret/South of Carteret
MW-35	6/4/2014	7.82	Carteret/South of Carteret
114MON24	6/4/2014	5.82	Carteret/South of Carteret
132-MW2A	6/4/2014	6.54	Carteret/South of Carteret
114-MW22A	6/4/2014	5.21	Carteret/South of Carteret
114-P1B-MW103S	6/18/2014	9.02	Carteret/South of Carteret
114-P1B-MW103S	10/8/2014	9.14	Carteret/South of Carteret
114-P1B-MW103S	12/3/2014	9.25	Carteret/South of Carteret
114-P1B-MW103S	4/16/2015	9.48	Carteret/South of Carteret
114-P1B-MW103S	4/16/2015	9.48	Carteret/South of Carteret
132-MW2A	4/16/2015	4.44	Carteret/South of Carteret
MW-34	4/16/2015	5.45	Carteret/South of Carteret
MW-35	4/16/2015	4.71	Carteret/South of Carteret
114-MW22A	9/16/2015	4.90	Carteret/South of Carteret
114-P1B-MW103S	9/16/2015	9.69	Carteret/South of Carteret
132-P3A-MW103S	9/16/2015	5.85	Carteret/South of Carteret
132-P3A-MW2	9/16/2015	4.98	Carteret/South of Carteret
143-P3A-MW101S	9/16/2015	5.19	Carteret/South of Carteret
MW-34	9/16/2015	7.38	Carteret/South of Carteret
MW-35	9/16/2015	5.83	Carteret/South of Carteret
132-MW2A	9/17/2015	3.76	Carteret/South of Carteret
132-P3A-MW102S	9/17/2015	4.87	Carteret/South of Carteret
132-P3A-MW104S	9/17/2015	5.99	Carteret/South of Carteret
132-P3A-MW3	10/5/2015	5.95	Carteret/South of Carteret
132-P3A-MW4	10/5/2015	7.58	Carteret/South of Carteret
132-P3A-MW5	10/5/2015	7.25	Carteret/South of Carteret
143-P3A-MW101S	12/2/2015	5.85	Carteret/South of Carteret
114-MW22A	12/8/2015	5.45	Carteret/South of Carteret
114-P1B-MW103S	12/8/2015	9.79	Carteret/South of Carteret
132-MW2A	12/8/2015	4.29	Carteret/South of Carteret
132-P3A-MW1	12/8/2015	6.39	Carteret/South of Carteret
132-P3A-MW102S	12/8/2015	5.40	Carteret/South of Carteret
132-P3A-MW103S	12/8/2015	6.78	Carteret/South of Carteret
132-P3A-MW104S	12/8/2015	6.85	Carteret/South of Carteret
132-P3A-MW2	12/8/2015	5.76	Carteret/South of Carteret
132-P3A-MW3	12/8/2015	5.85	Carteret/South of Carteret
132-P3A-MW4	12/8/2015	6.99	Carteret/South of Carteret
132-P3A-MW5	12/8/2015	5.84	Carteret/South of Carteret
MW-34	12/8/2015	7.88	Carteret/South of Carteret
MW-35	12/8/2015	6.47	Carteret/South of Carteret
114-MW22A	3/7/2016	6.57	Carteret/South of Carteret
114-P1B-MW103S	3/7/2016	10.60	Carteret/South of Carteret
132-MW2A	3/7/2016	5.94	Carteret/South of Carteret
132-P3A-MW1	3/7/2016	8.19	Carteret/South of Carteret
132-P3A-MW102S	3/7/2016	6.86	Carteret/South of Carteret
132-P3A-MW103S	3/7/2016	8.50	Carteret/South of Carteret
132-P3A-MW104S	3/7/2016	8.41	Carteret/South of Carteret
132-P3A-MW2	3/7/2016	7.48	Carteret/South of Carteret
132-P3A-MW3	3/7/2016	7.26	Carteret/South of Carteret
132-P3A-MW4	3/7/2016	8.26	Carteret/South of Carteret
132-P3A-MW5	3/7/2016	7.56	Carteret/South of Carteret
143-P3A-MW101S	3/7/2016	7.56	Carteret/South of Carteret
MW-34	3/7/2016	8.39	Carteret/South of Carteret
MW-35	3/7/2016	8.24	Carteret/South of Carteret
114-MW22A	6/13/2016	6.00	Carteret/South of Carteret
114-P1B-MW103S	6/13/2016	7.56	Carteret/South of Carteret
132-P3A-MW102S	6/13/2016	6.75	Carteret/South of Carteret
132-P3A-MW103S	6/13/2016	8.14	Carteret/South of Carteret

Appendix H
Groundwater Elevations - Western Portion of Site
Capillary Break Design - Final Report (Revision 2)
PPG, Jersey City, New Jersey

Well ID	Measurement Date	Groundwater Elevation (ft NAVD88)	Phase/Site
132-P3A-MW104S	6/13/2016	8.29	Carteret/South of Carteret
143-P3A-MW101S	6/13/2016	7.22	Carteret/South of Carteret
MW-34	6/13/2016	9.09	Carteret/South of Carteret
132-MW2A	6/14/2016	5.87	Carteret/South of Carteret
132-P3A-MW2	6/14/2016	7.30	Carteret/South of Carteret
132-P3A-MW3	6/14/2016	7.04	Carteret/South of Carteret
132-P3A-MW4	6/14/2016	8.21	Carteret/South of Carteret
MW-35	6/14/2016	7.79	Carteret/South of Carteret
132-P3A-MW5	6/15/2016	6.38	Carteret/South of Carteret
114-MW22A	9/8/2016	5.62	Carteret/South of Carteret
114-P1B-MW103S	9/8/2016	7.48	Carteret/South of Carteret
132-MW2A	9/8/2016	5.87	Carteret/South of Carteret
132-P3A-MW102S	9/8/2016	5.88	Carteret/South of Carteret
132-P3A-MW103S	9/8/2016	7.14	Carteret/South of Carteret
132-P3A-MW104S	9/8/2016	7.28	Carteret/South of Carteret
132-P3A-MW2	9/8/2016	6.27	Carteret/South of Carteret
132-P3A-MW4	9/8/2016	7.40	Carteret/South of Carteret
132-P3A-MW5	9/8/2016	5.97	Carteret/South of Carteret
143-P3A-MW101S	9/8/2016	6.00	Carteret/South of Carteret
MW-34	9/8/2016	6.74	Carteret/South of Carteret
MW-35	9/8/2016	6.82	Carteret/South of Carteret
114-MW22A	12/6/2016	6.99	Carteret/South of Carteret
114-P1B-MW103S	12/6/2016	10.70	Carteret/South of Carteret
132-MW2A	12/6/2016	6.88	Carteret/South of Carteret
132-P3A-MW102S	12/6/2016	7.87	Carteret/South of Carteret
132-P3A-MW103S	12/6/2016	9.29	Carteret/South of Carteret
132-P3A-MW104S	12/6/2016	9.57	Carteret/South of Carteret
132-P3A-MW2	12/6/2016	8.30	Carteret/South of Carteret
132-P3A-MW5	12/6/2016	7.91	Carteret/South of Carteret
143-P3A-MW101S	12/6/2016	9.10	Carteret/South of Carteret
MW-34	12/6/2016	9.82	Carteret/South of Carteret
MW-35	12/6/2016	8.98	Carteret/South of Carteret
MW3S	12/22/2003	11.12	Forrest St/Forrest Prop
MW6S	12/22/2003	7.48	Forrest St/Forrest Prop
MW3S	1/20/2004	10.13	Forrest St/Forrest Prop
MW6S	1/20/2004	6.66	Forrest St/Forrest Prop
MW3S	4/19/2004	11.40	Forrest St/Forrest Prop
MW6S	4/19/2004	7.42	Forrest St/Forrest Prop
MW3S	8/5/2005	9.36	Forrest St/Forrest Prop
MW6S	8/5/2005	5.65	Forrest St/Forrest Prop
MW3S	9/30/2005	8.33	Forrest St/Forrest Prop
MW6S	9/30/2005	4.83	Forrest St/Forrest Prop
MW3S	12/13/2005	10.25	Forrest St/Forrest Prop
MW6S	12/13/2005	6.58	Forrest St/Forrest Prop
MW3S	5/19/2006	8.13	Forrest St/Forrest Prop
MW6S	5/19/2006	6.94	Forrest St/Forrest Prop
MW3S	2/12/2007	9.29	Forrest St/Forrest Prop
114-MW23A	2/12/2007	9.70	Forrest St/Forrest Prop
MW3S	5/7/2007	10.43	Forrest St/Forrest Prop
MW6S	5/7/2007	7.18	Forrest St/Forrest Prop
114-MW23A	5/7/2007	10.58	Forrest St/Forrest Prop
MW3S	9/25/2007	9.61	Forrest St/Forrest Prop
MW6S	9/25/2007	5.90	Forrest St/Forrest Prop
MW3S	10/23/2007	9.71	Forrest St/Forrest Prop
MW6S	10/23/2007	5.72	Forrest St/Forrest Prop
114-MW23A	5/17/2011	9.55	Forrest St/Forrest Prop
MW3S	5/17/2011	10.33	Forrest St/Forrest Prop
MW6S	5/17/2011	6.51	Forrest St/Forrest Prop
MW6S	6/20/2011	6.51	Forrest St/Forrest Prop
114-MW23A	6/24/2011	10.50	Forrest St/Forrest Prop
MW3S	6/28/2011	10.53	Forrest St/Forrest Prop
114-MW23A	11/22/2011	10.50	Forrest St/Forrest Prop
MW6S	11/22/2011	6.55	Forrest St/Forrest Prop
MW3S	11/22/2011	10.03	Forrest St/Forrest Prop
114-MW26A	12/22/2011	6.97	Forrest St/Forrest Prop
114-MW23A	12/22/2011	10.20	Forrest St/Forrest Prop
MW6S	12/22/2011	6.61	Forrest St/Forrest Prop
MW3S	12/22/2011	9.95	Forrest St/Forrest Prop
114-MW28A	12/22/2011	7.65	Forrest St/Forrest Prop
114-MW27A	12/22/2011	6.23	Forrest St/Forrest Prop
114-MW24A	12/22/2011	6.92	Forrest St/Forrest Prop
114-MW25A	12/22/2011	6.53	Forrest St/Forrest Prop
114-MW23A	3/5/2013	8.52	Forrest St/Forrest Prop
114-MW24A	6/4/2014	5.94	Forrest St/Forrest Prop
114-MW25A	6/4/2014	5.78	Forrest St/Forrest Prop
114-MW27A	6/4/2014	5.55	Forrest St/Forrest Prop
114-MW30A	6/4/2014	6.71	Forrest St/Forrest Prop
114-MW27A	4/16/2015	5.76	Forrest St/Forrest Prop
114-MW24A	4/16/2015	6.09	Forrest St/Forrest Prop
114-MW25A	4/16/2015	5.47	Forrest St/Forrest Prop
114-MW30A	4/16/2015	6.88	Forrest St/Forrest Prop
114-P2B2-MW101S	4/16/2015	6.39	Forrest St/Forrest Prop

Appendix H
Groundwater Elevations - Western Portion of Site
Capillary Break Design - Final Report (Revision 2)
PPG, Jersey City, New Jersey

Well ID	Measurement Date	Groundwater Elevation (ft NAVD88)	Phase/Site
114-MW26A	9/16/2015	5.08	Forrest St/Forrest Prop
114-MW28A	9/16/2015	5.64	Forrest St/Forrest Prop
114-MW27A	9/16/2015	5.14	Forrest St/Forrest Prop
114-MW24A	9/16/2015	5.53	Forrest St/Forrest Prop
114-MW25A	9/16/2015	5.26	Forrest St/Forrest Prop
114-MW30A	9/16/2015	5.37	Forrest St/Forrest Prop
114-P2B2-MW101S	9/16/2015	5.56	Forrest St/Forrest Prop
114-MW36A	9/16/2015	5.04	Forrest St/Forrest Prop
114-MW37A	9/16/2015	5.55	Forrest St/Forrest Prop
114-MW38A	9/16/2015	6.57	Forrest St/Forrest Prop
114-MW27A	12/8/2015	5.25	Forrest St/Forrest Prop
114-MW24A	12/8/2015	5.92	Forrest St/Forrest Prop
114-MW25A	12/8/2015	5.57	Forrest St/Forrest Prop
114-MW30A	12/8/2015	6.04	Forrest St/Forrest Prop
114-P2B2-MW101S	12/8/2015	6.31	Forrest St/Forrest Prop
114-MW36A	12/8/2015	5.34	Forrest St/Forrest Prop
114-MW37A	12/8/2015	5.94	Forrest St/Forrest Prop
114-MW38A	12/8/2015	6.76	Forrest St/Forrest Prop
114-MW27A	3/7/2016	5.90	Forrest St/Forrest Prop
114-MW25A	3/7/2016	6.14	Forrest St/Forrest Prop
114-MW30A	3/7/2016	6.74	Forrest St/Forrest Prop
114-P2B2-MW101S	3/7/2016	7.70	Forrest St/Forrest Prop
114-MW36A	3/7/2016	5.96	Forrest St/Forrest Prop
114-MW37A	3/7/2016	6.47	Forrest St/Forrest Prop
114-P2A-MW102S	3/7/2016	7.40	Forrest St/Forrest Prop
114-P2A-MW103S	3/7/2016	7.43	Forrest St/Forrest Prop
114-P2B2-MW101S	6/13/2016	7.43	Forrest St/Forrest Prop
114-P2A-MW102S	6/13/2016	6.97	Forrest St/Forrest Prop
114-P2A-MW103S	6/13/2016	11.05	Forrest St/Forrest Prop
114-MW27A	6/14/2016	6.05	Forrest St/Forrest Prop
114-MW24A	6/14/2016	6.40	Forrest St/Forrest Prop
114-MW25A	6/14/2016	6.22	Forrest St/Forrest Prop
114-MW30A	6/14/2016	6.84	Forrest St/Forrest Prop
114-MW36A	6/14/2016	6.60	Forrest St/Forrest Prop
114-MW37A	6/14/2016	6.41	Forrest St/Forrest Prop
114-MW38A	6/14/2016	7.31	Forrest St/Forrest Prop
114-MW26A	6/15/2016	5.96	Forrest St/Forrest Prop
114-MW28A	6/15/2016	6.56	Forrest St/Forrest Prop
114-MW27A	9/8/2016	5.67	Forrest St/Forrest Prop
114-MW24A	9/8/2016	5.85	Forrest St/Forrest Prop
114-MW25A	9/8/2016	5.60	Forrest St/Forrest Prop
114-MW30A	9/8/2016	5.92	Forrest St/Forrest Prop
114-P2B2-MW101S	9/8/2016	6.30	Forrest St/Forrest Prop
114-MW36A	9/8/2016	6.02	Forrest St/Forrest Prop
114-MW37A	9/8/2016	6.05	Forrest St/Forrest Prop
114-MW38A	9/8/2016	6.87	Forrest St/Forrest Prop
114-P2A-MW102S	9/8/2016	6.23	Forrest St/Forrest Prop
114-P2A-MW103S	9/8/2016	6.24	Forrest St/Forrest Prop
114-MW27A	12/6/2016	6.08	Forrest St/Forrest Prop
114-MW24A	12/6/2016	6.89	Forrest St/Forrest Prop
114-MW25A	12/6/2016	6.55	Forrest St/Forrest Prop
114-P2B2-MW101S	12/6/2016	8.54	Forrest St/Forrest Prop
114-MW36A	12/6/2016	6.24	Forrest St/Forrest Prop
114-MW37A	12/6/2016	6.83	Forrest St/Forrest Prop
114-MW38A	12/6/2016	7.92	Forrest St/Forrest Prop
114-P2A-MW102S	12/6/2016	7.97	Forrest St/Forrest Prop
114-P2A-MW103S	12/6/2016	7.31	Forrest St/Forrest Prop
MW1A	12/22/2003	9.73	North of Carteret
MW3A	12/22/2003	11.55	North of Carteret
MW5A	12/22/2003	12.22	North of Carteret
MW1A	1/20/2004	9.30	North of Carteret
MW3A	1/20/2004	10.61	North of Carteret
MW5A	1/20/2004	12.22	North of Carteret
MW1A	9/30/2005	8.08	North of Carteret
MW3A	9/30/2005	9.58	North of Carteret
MW5A	9/30/2005	10.16	North of Carteret
MW12A	12/13/2005	11.39	North of Carteret
MW9A	12/13/2005	11.96	North of Carteret
MW1A	12/13/2005	9.03	North of Carteret
MW3A	12/13/2005	10.78	North of Carteret
MW5A	12/13/2005	11.65	North of Carteret
PZ8	12/13/2005	10.56	North of Carteret
PZ9	12/13/2005	10.62	North of Carteret
MW12A	05/19/2006	11.96	North of Carteret
MW9A	05/19/2006	12.29	North of Carteret
MW1A	05/19/2006	10.06	North of Carteret
MW3A	05/19/2006	13.19	North of Carteret
MW5A	05/19/2006	13.13	North of Carteret
PZ8	05/19/2006	10.58	North of Carteret
PZ9	05/19/2006	6.53	North of Carteret
114-MW21A	2/12/2007	8.78	North of Carteret
MW12A	2/12/2007	10.38	North of Carteret

Appendix H
Groundwater Elevations - Western Portion of Site
Capillary Break Design - Final Report (Revision 2)
PPG, Jersey City, New Jersey

Well ID	Measurement Date	Groundwater Elevation (ft NAVD88)	Phase/Site
MW9A	2/12/2007	11.45	North of Carteret
MW1A	2/12/2007	8.34	North of Carteret
MW3A	2/12/2007	10.12	North of Carteret
MW5A	2/12/2007	10.70	North of Carteret
PZ8	2/12/2007	10.39	North of Carteret
114-MW21A	5/7/2007	10.64	North of Carteret
MW12A	5/7/2007	11.59	North of Carteret
MW9A	5/7/2007	12.31	North of Carteret
MW1A	5/7/2007	9.35	North of Carteret
MW3A	5/7/2007	11.15	North of Carteret
MW5A	5/7/2007	11.57	North of Carteret
PZ8	5/7/2007	10.85	North of Carteret
PZ9	5/7/2007	11.15	North of Carteret
MW5A	5/17/2011	10.45	North of Carteret
MW1A	5/17/2011	10.05	North of Carteret
MW12A	5/17/2011	6.57	North of Carteret
MW3A	5/17/2011	9.30	North of Carteret
114-MW21A	5/17/2011	8.22	North of Carteret
MW1A	6/13/2011	9.15	North of Carteret
MW3A	6/14/2011	9.62	North of Carteret
MW12A	6/23/2011	11.79	North of Carteret
MW5A	6/28/2011	10.67	North of Carteret
114-MW21A	6/30/2011	8.76	North of Carteret
MW1A	11/22/2011	9.26	North of Carteret
MW5A	11/22/2011	11.47	North of Carteret
MW3A	11/22/2011	9.93	North of Carteret
114-MW21A	11/22/2011	9.66	North of Carteret
MW12A	11/22/2011	11.49	North of Carteret
MW-MORRIS1A	3/5/2013	7.01	North of Carteret
MW-33	3/5/2013	7.11	North of Carteret
MW-32	3/5/2013	8.22	North of Carteret
MW-31A	3/5/2013	7.61	North of Carteret
114-MW21A	3/5/2013	9.32	North of Carteret
MW-33	4/23/2013	6.52	North of Carteret
MW-MORRIS1A	4/23/2013	5.03	North of Carteret
MW-32	4/24/2013	5.52	North of Carteret
114-P1A-MW101S	5/29/2014	6.23	North of Carteret
114-P1B-MW102S	5/30/2014	7.59	North of Carteret
MW-MORRIS1A	6/4/2014	5.75	North of Carteret
114MON33	6/4/2014	10.11	North of Carteret
114MON32	6/4/2014	10.10	North of Carteret
MW-32	6/4/2014	8.51	North of Carteret
MW-33	6/4/2014	9.27	North of Carteret
114-P1B-MW104S	6/4/2014	11.29	North of Carteret
114-P1B-MW101S	6/4/2014	10.38	North of Carteret
MW-31A	6/4/2014	10.10	North of Carteret
114-P1A-MW101S	6/4/2014	6.72	North of Carteret
GPS-MW1S	6/4/2014	6.04	North of Carteret
GPS-MW3S	6/4/2014	8.91	North of Carteret
GPS-MW4S	6/4/2014	9.87	North of Carteret
GPS-MW7S	6/4/2014	9.91	North of Carteret
GPS-MW5S	6/4/2014	6.66	North of Carteret
GPS-MW2S	6/4/2014	5.67	North of Carteret
114-P1A-MW101S	6/6/2014	5.02	North of Carteret
GPS-IW1S	6/6/2014	8.79	North of Carteret
GPS-IW2S	6/6/2014	2.63	North of Carteret
GPS-MW5S	6/6/2014	6.40	North of Carteret
GPS-MW6S	6/6/2014	8.95	North of Carteret
GPS-MW7S	6/6/2014	9.70	North of Carteret
GPS-PZ1S	6/6/2014	7.66	North of Carteret
GPS-PZ2S	6/6/2014	8.12	North of Carteret
GPS-PZ3S	6/6/2014	9.03	North of Carteret
GPS-PZ4S	6/6/2014	9.21	North of Carteret
GPS-PZ5S	6/6/2014	9.35	North of Carteret
114-P1B-MW104S	6/17/2014	9.65	North of Carteret
114-P1B-MW101S	6/18/2014	9.47	North of Carteret
114-P1A-MW101S	6/19/2014	5.19	North of Carteret
GPS-IW1S	6/19/2014	4.59	North of Carteret
GPS-IW2S	6/19/2014	3.24	North of Carteret
GPS-MW5S	6/19/2014	5.17	North of Carteret
GPS-MW7S	6/19/2014	7.65	North of Carteret
GPS-PZ1S	6/19/2014	7.02	North of Carteret
GPS-PZ2S	6/19/2014	6.63	North of Carteret
GPS-PZ3S	6/19/2014	9.11	North of Carteret
GPS-PZ4S	6/19/2014	9.11	North of Carteret
GPS-PZ5S	6/19/2014	9.42	North of Carteret
114-P1B-MW102S	6/20/2014	6.56	North of Carteret
GPS-MW6S	6/20/2014	6.73	North of Carteret
114-P1A-MW101S	7/16/2014	7.36	North of Carteret
GPS-IW1S	7/16/2014	4.46	North of Carteret
GPS-IW2S	7/16/2014	5.90	North of Carteret
GPS-MW5S	7/16/2014	5.87	North of Carteret

Appendix H
Groundwater Elevations - Western Portion of Site
Capillary Break Design - Final Report (Revision 2)
PPG, Jersey City, New Jersey

Well ID	Measurement Date	Groundwater Elevation (ft NAVD88)	Phase/Site
GPS-MW7S	7/16/2014	5.20	North of Carteret
GPS-PZ1S	7/16/2014	7.66	North of Carteret
GPS-PZ2S	7/16/2014	6.88	North of Carteret
GPS-PZ3S	7/16/2014	7.26	North of Carteret
GPS-PZ4S	7/16/2014	8.33	North of Carteret
GPS-PZ5S	7/16/2014	9.39	North of Carteret
GPS-MW6S	7/17/2014	5.78	North of Carteret
114-P1B-MW104S	7/18/2014	6.18	North of Carteret
114-P1A-MW101S	8/6/2014	5.71	North of Carteret
GPS-IW1S	8/6/2014	5.86	North of Carteret
GPS-PZ1S	8/6/2014	7.91	North of Carteret
GPS-PZ2S	8/6/2014	8.10	North of Carteret
GPS-PZ3S	8/6/2014	8.58	North of Carteret
GPS-PZ4S	8/6/2014	8.75	North of Carteret
GPS-PZ5S	8/6/2014	8.99	North of Carteret
GPS-IW2S	8/7/2014	5.94	North of Carteret
GPS-MW5S	8/7/2014	4.97	North of Carteret
GPS-MW6S	8/7/2014	4.28	North of Carteret
GPS-MW7S	8/7/2014	6.96	North of Carteret
114-P1A-MW101S	10/7/2014	5.78	North of Carteret
114-P1B-MW101S	10/7/2014	7.80	North of Carteret
GPS-IW1S	10/7/2014	7.51	North of Carteret
GPS-IW2S	10/7/2014	8.48	North of Carteret
GPS-MW5S	10/7/2014	6.40	North of Carteret
GPS-PZ1S	10/7/2014	7.34	North of Carteret
GPS-PZ2S	10/7/2014	7.83	North of Carteret
GPS-PZ3S	10/7/2014	8.11	North of Carteret
GPS-PZ4S	10/7/2014	8.43	North of Carteret
GPS-PZ5S	10/7/2014	8.19	North of Carteret
114-P1A-MW101S	10/8/2014	5.96	North of Carteret
114-P1B-MW102S	10/8/2014	6.56	North of Carteret
114-P1B-MW104S	10/8/2014	8.68	North of Carteret
GPS-MW6S	10/8/2014	9.29	North of Carteret
GPS-MW7S	10/8/2014	9.00	North of Carteret
MW-MORRIS1A	10/9/2014	4.31	North of Carteret
114-P1C-MW101S	11/18/2014	3.96	North of Carteret
114-P2B1-MW102S	11/20/2014	4.37	North of Carteret
114-P1A-MW101S	12/2/2014	7.02	North of Carteret
114-P1B-MW101S	12/3/2014	8.09	North of Carteret
114-P1B-MW104S	12/3/2014	9.00	North of Carteret
GPS-MW5S	1/5/2015	8.47	North of Carteret
114-P1A-MW101S	1/6/2015	8.33	North of Carteret
GPS-IW1S	1/6/2015	9.46	North of Carteret
GPS-IW2S	1/6/2015	9.69	North of Carteret
GPS-MW7S	1/6/2015	10.06	North of Carteret
GPS-PZ1S	1/6/2015	8.76	North of Carteret
GPS-PZ2S	1/6/2015	9.33	North of Carteret
GPS-PZ3S	1/6/2015	9.61	North of Carteret
GPS-PZ4S	1/6/2015	9.63	North of Carteret
GPS-PZ5S	1/6/2015	9.79	North of Carteret
GPS-MW6S	1/14/2015	9.38	North of Carteret
114-MC-MW101S	4/16/2015	6.26	North of Carteret
114-MC-MW102S	4/16/2015	6.44	North of Carteret
114-P1A-MW101S	4/16/2015	7.65	North of Carteret
114-P1B-MW101S	4/16/2015	9.29	North of Carteret
114-P1B-MW102S	4/16/2015	7.27	North of Carteret
114-P1B-MW104S	4/16/2015	10.13	North of Carteret
114-P1C-MW101S	4/16/2015	7.11	North of Carteret
MW-31A	4/16/2015	9.78	North of Carteret
MW-MORRIS1A	4/16/2015	7.06	North of Carteret
114MON33	4/16/2015	8.50	North of Carteret
114MON32	9/16/2015	7.78	North of Carteret
114-MC-MW101S	9/16/2015	5.52	North of Carteret
114-MC-MW102S	9/16/2015	5.60	North of Carteret
114-P1A-MW101S	9/16/2015	6.91	North of Carteret
114-P1B-MW101S	9/16/2015	9.47	North of Carteret
114-P1B-MW102S	9/16/2015	6.84	North of Carteret
114-P1B-MW104S	9/16/2015	10.01	North of Carteret
114-P1C-MW101S	9/16/2015	6.20	North of Carteret
114-P2B1-MW102S	9/16/2015	6.01	North of Carteret
MW-31A	9/16/2015	9.13	North of Carteret
MW-MORRIS1A	9/16/2015	5.76	North of Carteret
114MON33	9/16/2015	7.80	North of Carteret
114REL8	10/5/2015	9.39	North of Carteret
114REL9	10/5/2015	8.66	North of Carteret
114MON32	12/8/2015	8.83	North of Carteret
114-MC-MW101S	12/8/2015	6.41	North of Carteret
114-MC-MW102S	12/8/2015	6.74	North of Carteret
114-P1A-MW101S	12/8/2015	7.55	North of Carteret
114-P1B-MW101S	12/8/2015	9.58	North of Carteret
114-P1B-MW102S	12/8/2015	7.51	North of Carteret
114-P1B-MW104S	12/8/2015	10.24	North of Carteret

Appendix H
Groundwater Elevations - Western Portion of Site
Capillary Break Design - Final Report (Revision 2)
PPG, Jersey City, New Jersey

Well ID	Measurement Date	Groundwater Elevation (ft NAVD88)	Phase/Site
114-P1C-MW101S	12/8/2015	7.01	North of Carteret
114-P2B1-MW102S	12/8/2015	6.84	North of Carteret
114REL8	12/8/2015	8.70	North of Carteret
114REL9	12/8/2015	6.46	North of Carteret
GPS-MW1S	12/8/2015	7.79	North of Carteret
MW-31A	12/8/2015	10.04	North of Carteret
MW-MORRIS1A	12/8/2015	7.33	North of Carteret
114MON33	12/8/2015	8.98	North of Carteret
114MON32	3/7/2016	9.74	North of Carteret
114-MC-MW101S	3/7/2016	8.14	North of Carteret
114-MC-MW102S	3/7/2016	8.22	North of Carteret
114-P1A-MW101S	3/7/2016	8.25	North of Carteret
114-P1B-MW101S	3/7/2016	9.56	North of Carteret
114-P1B-MW102S	3/7/2016	8.36	North of Carteret
114-P1B-MW104S	3/7/2016	10.23	North of Carteret
114-P1C-MW101S	3/7/2016	8.11	North of Carteret
114-P2B1-MW102S	3/7/2016	8.01	North of Carteret
114REL8	3/7/2016	9.15	North of Carteret
114REL9	3/7/2016	8.16	North of Carteret
MW-31A	3/7/2016	10.54	North of Carteret
MW-MORRIS1A	3/7/2016	8.36	North of Carteret
114MON33	3/7/2016	9.69	North of Carteret
114MON32	6/13/2016	9.85	North of Carteret
114-MC-MW101S	6/13/2016	7.84	North of Carteret
114-MC-MW102S	6/13/2016	7.92	North of Carteret
114-P1A-MW101S	6/13/2016	8.21	North of Carteret
114-P1B-MW101S	6/13/2016	10.08	North of Carteret
114-P1B-MW102S	6/13/2016	8.00	North of Carteret
114-P1C-MW101S	6/13/2016	7.92	North of Carteret
114-P2B1-MW102S	6/13/2016	2.63	North of Carteret
114REL8	6/13/2016	9.24	North of Carteret
114REL9	6/13/2016	8.84	North of Carteret
MW-MORRIS1A	6/13/2016	8.38	North of Carteret
114MON33	6/13/2016	11.36	North of Carteret
114-P1B-MW104S	6/14/2016	10.80	North of Carteret
MW-31A	6/14/2016	10.64	North of Carteret
114MON32	9/8/2016	7.97	North of Carteret
114-MC-MW101S	9/8/2016	6.45	North of Carteret
114-MC-MW102S	9/8/2016	6.98	North of Carteret
114-P1A-MW101S	9/8/2016	7.61	North of Carteret
114-P1B-MW101S	9/8/2016	9.84	North of Carteret
114-P1B-MW102S	9/8/2016	7.00	North of Carteret
114-P1B-MW104S	9/8/2016	10.75	North of Carteret
114-P1C-MW101S	9/8/2016	6.91	North of Carteret
114-P2B1-MW102S	9/8/2016	6.72	North of Carteret
114REL8	9/8/2016	7.60	North of Carteret
114REL9	9/8/2016	6.13	North of Carteret
MW-31A	9/8/2016	9.74	North of Carteret
MW-MORRIS1A	9/8/2016	6.98	North of Carteret
114MON33	9/8/2016	8.17	North of Carteret
114MON32	12/6/2016	10.30	North of Carteret
114-MC-MW101S	12/6/2016	9.01	North of Carteret
114-MC-MW102S	12/6/2016	8.64	North of Carteret
114MON33	12/6/2016	10.30	North of Carteret
114-P1A-MW101S	12/6/2016	8.73	North of Carteret
114-P1B-MW101S	12/6/2016	8.99	North of Carteret
114-P1B-MW102S	12/6/2016	9.19	North of Carteret
114-P1B-MW104S	12/6/2016	10.30	North of Carteret
114-P1C-MW101S	12/6/2016	8.66	North of Carteret
114-P2B1-MW102S	12/6/2016	3.47	North of Carteret
114REL8	12/6/2016	9.68	North of Carteret
114REL9	12/6/2016	9.17	North of Carteret
MW-31A	12/6/2016	11.06	North of Carteret
MW-MORRIS1A	12/6/2016	6.39	North of Carteret

Notes:

ft NAVD88 - feet North American Verical Datum of 1988

prop - properties

st - street